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THE ELECTRICAL MANUFACTURE OF CARBON BLACK

BY

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THE ELECTRICAL MANUFACTURE OF CARBON BLACK

By J. J. JAKOSKY.

INTRODUCTION.

Existing and proposed legislation against the present method of producing carbon black from natural gas[1] and the continually increasing demand for the gas for other purposes indicate that the supply of carbon black may gradually decrease and that new methods for its production should be developed. In the course of investigations of the effects of high-voltage electrical discharges on hydrocarbons, it was noted that, under certain conditions, natural gas could be decomposed and carbon black produced. The author therefore studied the effects of several types of electrical discharge on natural gas and on liquid hydrocarbons and other oils in order to ascertain the fundamental factors in the reactions. In the study of natural gas, the possible influence of these factors on the recovery of a larger part of the carbon content of the gas than is now possible was investigated.

CHARACTERISTICS DIFFERENTIATING CARBON BLACK FROM LAMPBLACK.

Carbon black, an allotropic form of carbon, is a fluffy, finely divided black pigment that at present is produced[2] by allowing the yellow flame of natural gas burning with an insufficient supply of air to impinge against a cool metal surface. The black collects on this surface, whence it is removed by mechanical scrapers into hoppers that have screw conveyors to carry the "black" to the packing house, where it is bolted, sacked, and prepared for shipment.

Lampblack is usually made by burning heavy oil, tar, creosote, or other material in large settling chambers with an insufficient supply of air. The soot settles as lampblack on the floor of the chamber. Carbon black and lampblack differ in physical properties, and have widely different uses in the industries. Chemically, they do not

[1] Neal, R. O., and Perrott, G. St. J., Carbon black—its manufacture, properties, and uses: Bureau of Mines, Bull. 192, 1922, 93 pp.; Perrott, G. St. J., and Thiessen, R., Carbon black, its properties and uses: Jour. Ind. Eng. Chem., vol. 12, No. 4, April, 1920, p. 324.

[2] Perrott and Thiessen, work cited.

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differ much, as each is essentially carbon in a finely divided state; but lampblack usually contains more empyreumatic and soluble material. Carbon black contains 85 to 95 per cent amorphous carbon, 0.3 to 1 per cent hydrogen (in the form of volatile hydrocarbons and adsorbed gases), 0.5 to 10 per cent moisture, and 1.0 to 10 per cent oxygen (in the form of volatile gums, adsorbed carbon monoxide, and carbon dioxide).

The physical differences between carbon black and lampblack are decided. In color the former is a deep velvety black, whereas the latter has a grayish hue. This difference in color seems largely due to differences in the size of the constituent particles; those of carbon black are much the more finely divided. This finer subdivision accounts for the greater covering power and tinting strength.

GENERAL USES AND CONSUMPTION.

Ink made from carbon black is much better for use in the present high-speed printing presses, which require a very fluid, "long" ink, and for lithographic and offset work in the slow-speed presses which use a "short" slow-flowing ink. An ink of the right consistence and color for such work can not be made from lampblack because of its grayish hue. About 20 to 25 per cent of the present output of carbon black in the United States is used in printing and the allied industries.

The rapid growth of the automotive industry has created an extensive market for carbon black as a toughener in rubber. Prior to the World War zinc oxide was used largely for that purpose, but the rising price of this material during the early part of the war brought in a substitute—carbon black. The substitute soon proved to be superior and its use increased enormously. Addition of carbon black as a reinforcing agent has given greater elasticity and tensile strength to the rubber of rubber tires, and is said to have increased tire mileage 20 to 30 per cent. It is also generally believed that the opaqueness of carbon black to light has increased the life of rubber, presumably due to its preventing light, especially ultra-violet light, from penetrating rubber. Approximately 30 to 35 per cent[3] of the total output of carbon black in the United States is used in the rubber industry in the manufacture of automobile tires, hard rubber, electrical insulation, radio and auxiliary high-frequency and high-voltage equipment, and so forth.

About 10 to 15 per cent of the carbon black produced is used in making high-grade paints and enamels and in such miscellaneous products as stove and shoe blacking, phonograph records, black leather, typewriter ribbons, carbon-copy papers, carriage cloths, oil-

[3] Sievers, E. G., Carbon black produced from natural gas in 1921: U. S. Geol. Survey, Mineral Resources of the United States, 1921, Pt. II, 1922, p. 35.

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cloths, linoleum, black opaque photographic papers, celluloid cement, wall tints and colors, marking inks and pencils, and artificial tile.

A comparatively large potential consumption of carbon black will be in liquid-oxygen explosives.[4] A cartridge of carbonaceous material—preferably carbon black—is soaked in liquid oxygen for a few minutes, charged into the drill hole in rock or ore, and exploded by a detonator in the usual manner.

About 15 to 25 per cent of the carbon black made in the United States is exported for use in the same industries as in this country. Large quantities go to England, France, and Germany for rubber compounding and to Japan and China for manufacture into "India" and other inks, paints, and enamels.

Plates IV, *a*, to VIII, *b* (p. 36), are photomicrographs of lampblack and carbon black. They show that the particles of carbon black are smaller than those of lampblack.

Present industrial plants that manufacture carbon black from natural gas recover 0.8 to 2 pounds of carbon black per 1,000 cubic feet of gas consumed, or 2.5 to 6 per cent of the total chemically combined carbon in the gas. In most plants higher yields are obtained at the expense of quality. It should be noted, however, that the present methods involve burning the gas as a luminous flame in which the carbon particles are heated to incandescence; thus a considerable part of the gas is consumed as a source of heat. If this heat or energy can be supplied from some other source, or if a more efficient method of applying the energy from part of the gas to the decomposition of the remainder can be devised that will give a black of proper quality, then a greater yield of carbon black per 1,000 cubic feet of gas can be expected.

DISSOCIATION AND RECOVERY OF CARBON BLACK.

The quality of the black recovered by dissociation of the gas depends largely on the pyrolytic conditions in the dissociation zone. Two things are essential for the production of a good quality of carbon black, a temperature high enough to dissociate the gas with a dissociation velocity sufficient to make the process efficient and economically feasible, and a means of quickly cooling the carbon black and removing it from the hot zone before agglomeration or polymerization of the finely divided particles can take place.

Present experimental data seem to indicate that immediately after the dissociation of a hydrocarbon the carbon particles liberated are

[4] Kuryla, M. H., and Clevenger, G. H., Liquid-oxygen explosives at Pachuca, Mexico: Trans. Am. Inst. Min. and Met. Eng., 1923, 51 pp.; Rice, Geo. S., Development of liquid-oxygen explosives during the war: Tech. Paper 243, Bureau of Mines, 1920, 46 pp.; Paul, J. W., Howell, S. P., and Sherrick, J. L., Progress in use of liquid-oxygen explosives: Tech. Paper 294, Bureau of Mines, 1923, 91 pp.

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ultramicroscopic, but the longer they remain in the heated zone the larger becomes their average size. Those processes that remove the black from the heated zone most quickly yield the highest quality of black. The higher the temperature the more quickly must the black be removed from the hot zone to keep the particles from agglomerating.

In practically all the thermal processes of manufacture advocated at present dissociation is obtained by passing the gas through heated tubes or hot brick checkerwork. The gas that first comes in contact with the hot tubes is first dissociated, and the liberated carbon is carried in suspension as the gas passes through the remainder of the heating zone. For any given apparatus, the quicker the passage of the gas through the apparatus the higher the quality of the black recovered—and the lower the proportion of gas dissociated. In most thermal processes, in order to insure enough dissociation of the gas to make them efficient, the time during which the gas must remain in the heated zone is longer than that allowed for the production of a good quality of black. In a number of thermal processes means are provided for quickly cooling the gases on their exit from the hot zone. In his examination of samples of black made by these processes, however, the writer found that the cooling gave no improvement in the quality of the black, because the damage to quality had been done before the gas left the hot zone.

Because of the quickness with which the carbon must be removed from the heated zone, the author in his experiments sought to have the temperature gradient between the hot dissociating zone and the cooling zone as steep as possible. The electric arc fulfills this requirement well.. In the arc and at its surface the temperature is extremely high, whereas a very short distance (probably a few millimeters) from the surface of the arc the temperature is not much higher than ordinary room temperature. Experiments showed that the temperature of the arc decidedly affects the quality of the carbon black—a point described in detail later.

SCOPE OF REPORT.

The experiments described in this paper are grouped into two distinct divisions, those dealing with hydrocarbons that are gases or vapors at ordinary temperatures and those dealing with liquids.

ACKNOWLEDGMENTS.

The writer thanks F. B. Tough, N. A. C. Smith, M. B. Cooke, D. A. Lyon, A. C. Fieldner, C. M. Bouton, J. D. Davis, W. M. Myers, L. C. Ilsley, G. W. Jones, and other present and former members of the Bureau of Mines, including Dr. E. W. Dean; and acknowledges

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the helpful suggestion of R. C. Tolman, of the California Institute of Technology, C. J. Rodman, of the Westinghouse Electric Manufacturing Co., and F. G. Cottrell, of the National Research Council. M. B. Cooke made the oil analyses and G. W. Jones made the gas analyses. Reinhardt Thiessen examined the black and provided the photomicrographs shown in Plates IV to VIII (p. 36). The completed manuscript was read by H. M. von Bernewitz. Acknowledgment is also made of samples of pine tar and other materials supplied by H. D. Butts, manufacturers' agent, Pittsburgh, Pa. F. E. Donath, H. A. Dent, W. A. Jacobs, P. A. Collins, and A. D. Bauer assisted in the construction and assembly of apparatus and equipment. The many services of these associates are heartily acknowledged.

APPARATUS AND EQUIPMENT FOR THE NATURAL-GAS EXPERIMENTS.

Pittsburgh natural gas was used; its chemical composition is as follows:

Composition of Pittsburgh natural gas used during experiments.

Carbon dioxide (CO_2)	0.0
Ethylene (C_2H_4)	[a] trace.
Oxygen (O_2)	0.0
Hydrogen (H_2)	[a] trace.
Carbon monoxide (CO)	[a] trace.
Methane (CH_4)	86.1
Ethane (C_2H_6)	12.1
Nitrogen (N_2)	1.8

[a] Presence of CO, H_2, and C_2H_4 is due to small amount of artificial gas mixed with the natural gas.

The gas flowed through the train of apparatus shown diagrammatically in Figure 1. It was measured with a wet meter, given a preliminary drying by bubbling through concentrated sulphuric acid, passed through a tube containing glass wool to remove acid spray, and finally dried by passage through a phosphoric anhydride tube 36 inches long and 5/8 inch in diameter. The rate of flow was regulated with a cock and the flow meter.

ELECTRICAL APPARATUS.

Figure 2 shows diagrammatically the electrical apparatus and connections. The equipment consisted essentially of a 15-kv.a. distributed-shell type, step-down transformer; voltage switch for 110, 220, or 440 volts; adjustable impedance coil; primary switch, controlling eight taps on the step-up transformer primary; 10-kv.a. step-up transformer, rectangular-core type; and voltmeter, ammeter, and wattmeter. The secondary of the step-up transformer was con-

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structed in four pies which allowed the coils to be connected in series, series-multiple, or multiple. This arrangement, with the voltage regulation on the primary circuit, allowed the use of voltages ranging from about 2,000 to as high as 150,000 volts.

An ammeter A_1 was placed in the primary circuit of the transformer, and the product of its reading by that of the voltmeter V_1

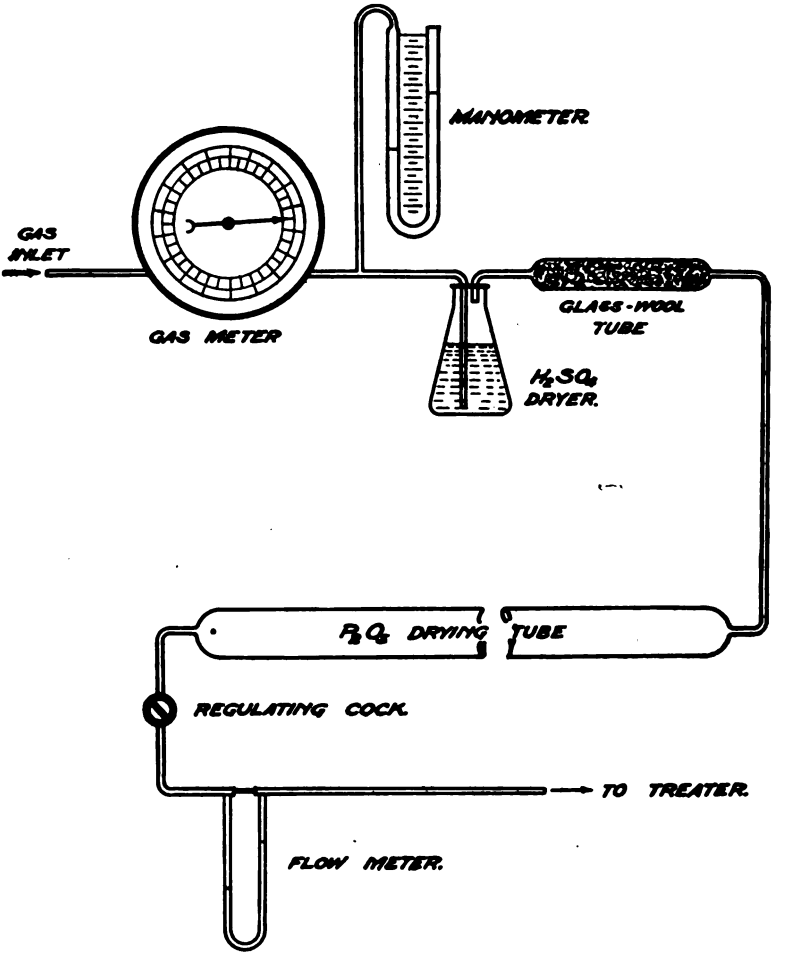

FIGURE 1.—Diagram of apparatus and equipment used in the natural-gas experiments.

across the line ahead of the reactance coil indicated the apparent rate of power. The product of the ammeter reading and of the voltmeter V_2 directly across the transformer primary indicated approximately the power through the transformer (the load on the secondary having practically unity power factor). The approximate power factor of the circuit, neglecting the comparatively small losses in the reactance coil and elsewhere, was calculated by dividing the second

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value by the first. The power factor of the entire circuit ranged from about 0.2 to 0.4. The arc across the secondary circuit was practically a straight short circuit on the transformer and necessitated a large reactance. The reactance was connected in the primary side of the transformer in order to give a simpler design than would have been necessary if the reactance had been in the secondary or high-voltage circuit.

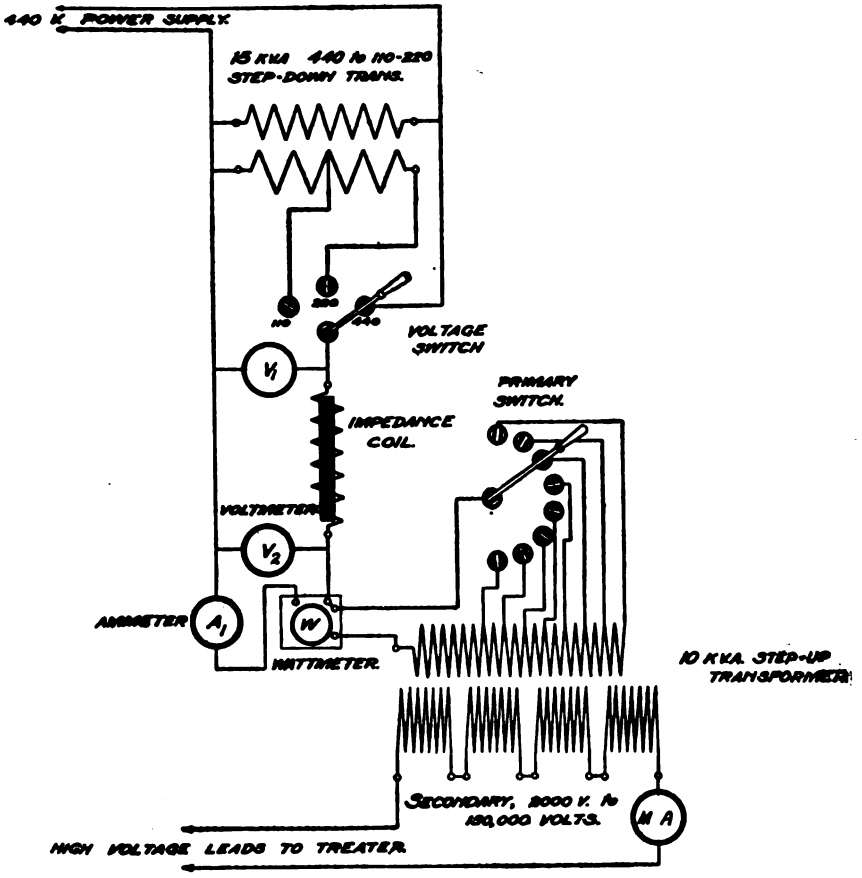

FIGURE 2.—Diagram of electrical connections.

The integrating watt-hour meter W was, as indicated, connected between the reactance coil and the primary of the transformer in order to measure only the actual power used by the transformer. The kilowatt hours per pound of black recovered was calculated from the wattmeter readings and the weight of actual carbon black recovered.

One side of the secondary circuit was grounded. A milliammeter was placed in the grounded side of the circuit, and the approxi-

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mate voltage of the secondary circuit was calculated by dividing the actual wattage flow in the primary circuit by the milliamperes flowing in the secondary circuit.

PRELIMINARY EXPERIMENTS ON PRODUCTION OF CARBON BLACK FROM NATURAL GAS.

EXPERIMENTS WITH NITROGEN-FIXATION APPARATUS.

At the start of the investigations it seemed advisable to try apparatus patterned somewhat after different types of apparatus for the electrical fixation of nitrogen. The dissociation of natural gas for recovery of a good grade of carbon black and the production of ammonia from nitrogen and hydrogen in the arc seem to require similar conditions—a good contact of the gases with the arc and a rapid cooling or chilling of the gases after contact. Numerous attempts to obtain smooth operation and high yield with such equipment proved unsuccessful, but many of the experiments were valuable as indicating the essential factors in proper control of conditions and design of apparatus. A brief description of the experiments follows.

EXPERIMENTS WITH THE PAULING-TYPE "HORN" GAP.

An apparatus similar to that used in the Pauling nitrogen-fixation process was constructed. The electrodes were horn shaped, like the horn gaps used on high-voltage transmission lines to protect against high-voltage surges and lighting. In air or other easily ionized gas the arc starts at the bottom, where the gap is shortest, and is deformed and carried upward by the heat and the rapid stream of incoming air. A fresh arc strikes at every reversal of the alternating current and the rapid succession of arcs produces a sheet of flame. When operated in air this type of apparatus gave a broad extended surface of flame, but it was not satisfactory in natural gas—evidently because the quenching action of the hydrogen-methane mixture kept the arc from spreading out and traveling upward. Difficulty was encountered in preventing carbon "trees" from building out near the bottom of the horns, where the arc stayed, and shortening the gap. A number of attempts were made to utilize this form of gap with different gap lengths and with voltages from 2,000 to 70,000 at 60 cycles, but without much success.

EXPERIMENTS WITH MAGNETICALLY SPREAD ARC.

Considerable time was spent in experiments with an apparatus similar to the Birkeland-Eyde magnetically spread arc for nitrogen fixation. The electromagnets and the treating tube used for these experiments are shown in Plates I and II, pages 16 and 17. There

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was little difficulty in extending the arc in an atmosphere of air, and obtaining a large flat disk of flame. In natural gas, however, the arc would not spread much, although the data obtained seemed to indicate that the spread arc is beneficial, and that the actual energy required per pound of carbon black formed is less than when the arc is not extended. The power required for the formation of carbon apparently decreases with the extent of the arc or the flame surface exposed. In practically all tests the wattage required to produce the magnetic field nearly equals, or even exceeds, the energy used in the arc; consequently the net efficiency of the spread arc is much lower. The method seems to offer possibilities, however. An increased amperage in the high-voltage arc may allow a decrease in the exciting current for the magnets, and then result in a higher over-all efficiency. In a large apparatus taking a much heavier current the method would probably give higher efficiency, as in comparison with the heavy current the magnetic field utilized might be weak.

EXPERIMENTS WITH SCHONHERR-HESSBERGER PROCESS.

A type of arc and apparatus that would probably be very advantageous (on the assumption that the greater the amount of gas thrown into the arc the greater the decomposition) is that of the Hessberger type, in which an arc is started between one end (usually the bottom) of the treater tube and a short central electrode. In this set of experiments the discharge chamber consisted of a grounded vertical 2-inch pipe which served as one electrode. The gas inlet and insulating lead-in for the central electrode were fastened to the bottom of the pipe and the arc was started by bringing the central electrode in contact with the pipe. The air entered tangentially and in such a way as to "blow" the arc upward in the tube. When air passed through the tube little difficulty was encountered in drawing out a long arc, but when natural gas was used the arc was either completely "blown out" or else formed (provided a voltage high enough was used) between the central electrode and the nearest point on the vertical tube. The voltages used ranged from 2,000 to 70,000 at 60 cycles.

EXPERIMENTS WITH REVOLVING DISK.

A 1⅜-inch brass disk was perpendicularly mounted upon a small motor-driven shaft placed centrally within a 2-inch pyrex tube. The disk formed one electrode, and a one-eighth inch hollow copper rod, through which the gas entered near the edge of the disk, formed the other. The disk was revolved rapidly enough (in air) to "wrap" the arc around its periphery, and this speed depends largely on the diameter of the disk and the voltage used. The gas was discharged into the arc a little above the revolving disk and had to pass through the

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"spread" arc to reach the outlet of the pyrex tube. When natural gas was used the arc did not spread; instead, it discharged directly from the hollow rod to the near edge of the disk. Different discharge voltages and disk speeds were tried without success.

These experiments indicated that use of any of the preceding types of apparatus, or of any whose efficiency depended on "spreading" the arc, would be impracticable.

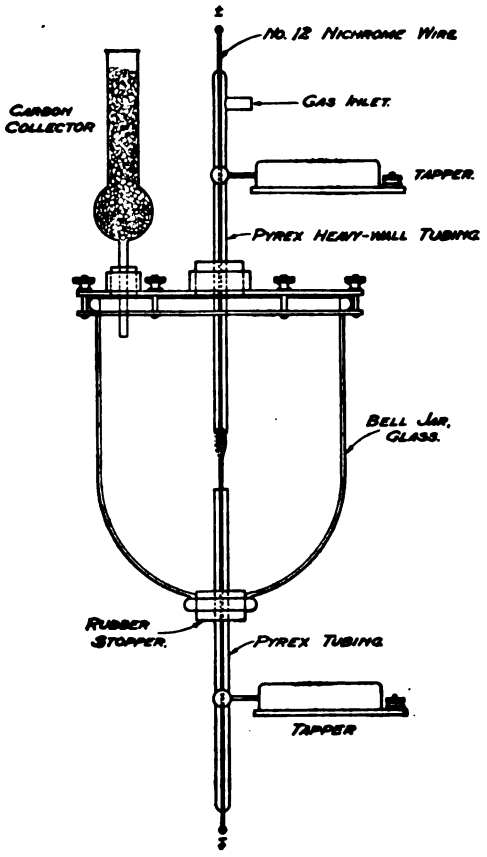

FIGURE 3.—Intermittent-type laboratory apparatus for treating gas.

EXPERIMENTS WITH INTERMITTENT-TYPE APPARATUS.

The intermittent type of apparatus was one of the first types tried after the experiments with the nitrogen-fixation type. Figure 3 shows the general construction. The electrodes were insulated with heavy-wall pyrex tubing, and the gas entered the apparatus through the annular space between the tubing and the upper nichrome electrode. The tubing extended about one-eighth inch beyond the end of the upper electrode in order that as much of the gas as possible should pass into the arc. Attempts to have the tube extend farther

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beyond the electrode in order to form more of a sleeve or shield around the arc encountered trouble from carbon deposition, the arc shifting over to the edge of the carbon-covered or "shorted" tube.

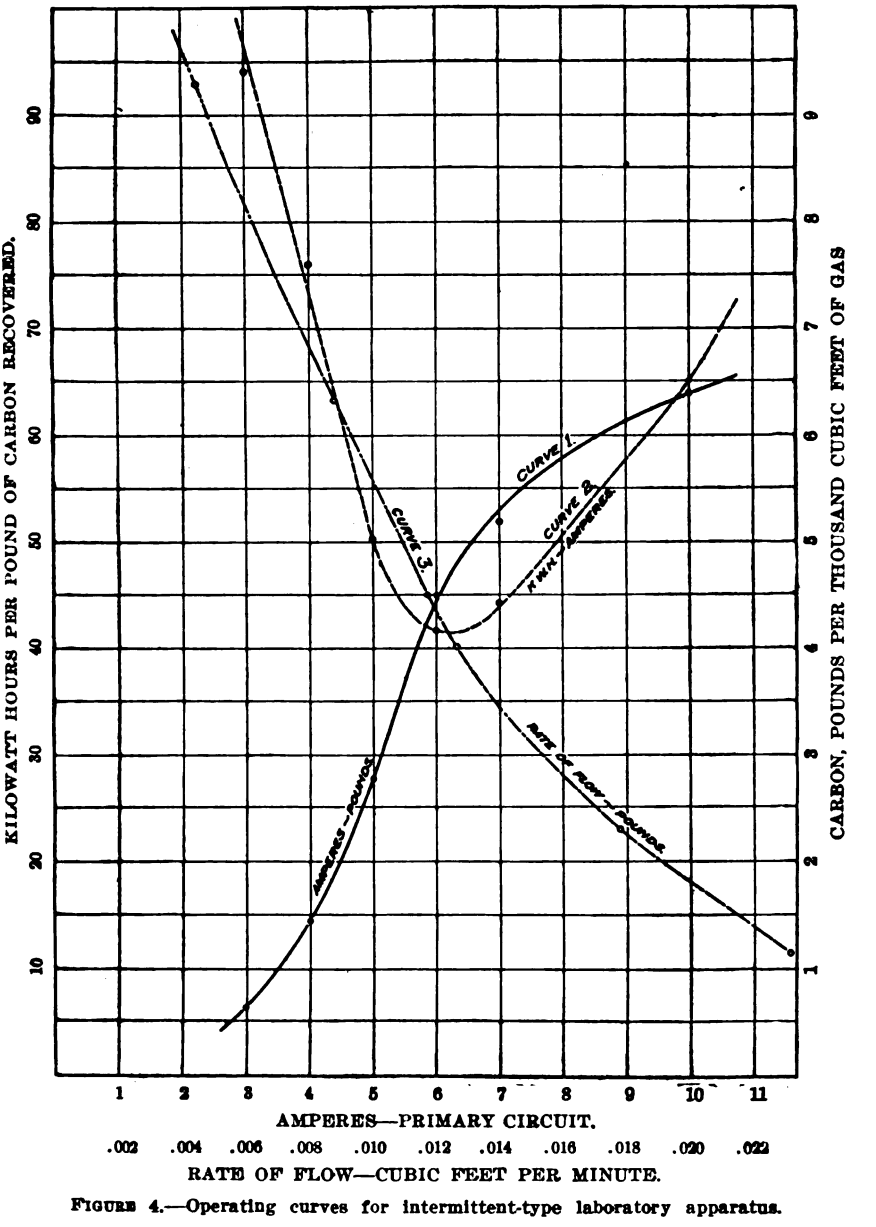

FIGURE 4.—Operating curves for intermittent-type laboratory apparatus.

Carbon formed during the decomposition of the gas settled on the walls of the bell jar and on the pyrex lead-in tubing. The apparatus could not be operated for periods longer than 30 to 45 minutes

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because of the short-circuiting of the electrodes by the deposited carbon. From the apparatus the treated gas flowed through a cotton filter and thence into the atmosphere. The filter caught considerable carbon whose weight was added to that of the carbon precipitated in the bell jar. Small quantities of naphthalene formed during the runs, as evidenced by crystals collected in the cotton filter.

The carbon collected in this apparatus resembled stringy cobwebs and could be easily broken up with a brush into very finely divided carbon black. If the carbon remained in the arc for any appreciable length of time it gradually changed from a finely divided to a hard gritty form that was dark gray and apparently crystalline. In order to keep the carbon out of the arc, and also to keep the electrodes clean, various mechanical devices were tried. The simplest, which was also fairly satisfactory, was a "buzzer" (a large electric bell with gong removed) tapping the electrodes. With a buzzer on each electrode, as shown in Figure 3, there was little trouble from carbon "trees" building out and causing short circuits.

OPERATING CHARACTERISTICS OF INTERMITTENT-TYPE APPARATUS.

The amount of carbon black recovered per unit volume of gas treated varies with the current, the rate of gas flow, and the type of apparatus. The curves in Figure 4 and data in Table 1 show the operating characteristics for the intermittent type of apparatus.

The curve 3, Figure 4, shows that the slower the rate of flow, or the longer the gas is exposed to the arc, the higher the percentage of carbon recovered. Curve 1 shows that, within certain values, as the current is increased, yield of carbon per unit volume of gas is increased, probably because of the higher temperature of the arc.

TABLE 1.—*Electrical decomposition of natural gas by intermittent-type apparatus.*

	Run No.—					
	C8	C9	C10	C11	C12	C13
Primary amperes	3.0	4.0	5.0	6.0	7.0	10.0
Primary volts	102	102	102	102	102	102
Indicated watt hours	306	408	510	612	714	1,020
Actual watt hours	70	95	128	140	165	232
Power factor	0.228	0.228	0.228	0.228	0.228	0.228
Duration of run, minutes	23.05	24.23	25.83	25.95	26.25	34.00
Gas treated, cubic feet	0.451	0.350	0.399	0.320	0.316	0.316
Total carbon recovered, grams	0.1300	0.2290	0.4991	0.6547	0.7434	0.918
Carbon, pounds per 1,000 cubic feet of gas	0.636	1.442	2.75	4.50	5.19	6.4
Kilowatt hours per pound of carbon recovered	94.0	76.0	50.2	41.8	44.2	65.0

	Run No.—					
	C14	C15	C16	C17	C18	C19
Primary amperes	6.0	6.0	6.0	6.0	6.0	6.0
Gas treated, cubic feet per minute	0.0044	0.0088	0.0117	0.0127	0.0177	0.0235
Carbon, pounds per 1,000 cubic feet of gas	9.30	6.35	4.50	4.01	2.30	1.15

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In practically all types of apparatus little or no carbon is formed when the current is decreased below a certain minimum value, possibly because of the low temperature of the arc. As the current is increased the temperature of the arc rises, and at a certain current flow, which depends upon the type of apparatus and arc, the decomposition of the methane begins. Increasing the current flow increases the yield of carbon, but a point is soon reached beyond which an increase in current gives only a slightly increased yield of black. This may be due to a combined effect produced by arc temperature and contact between gas and arc.

The rate of decomposition of the gas probably varies with the temperature—that is, the higher the temperature the greater the dissociation of the gas and the lower the percentage of undecomposed gas in equilibrium with its elements, although this reaction may be influenced by possible side reactions, such as the formation of naphthalene and products of condensation or polymerization. Offsetting the theoretically increased advantage gained by higher temperatures are two factors—the apparently poorer quality of the black produced and the lessened contact between gas and arc at the higher temperatures. At the higher temperature the molecules of gas have a greater velocity and by bombardment tend to prevent the easy entrance of cooler gaseous molecules. The surface area of the arc also increases only slightly beyond a certain amperage flow.

Since the amount of carbon recovered varies with the current, different types of apparatus have a somewhat different kilowatt-hour-ampere curve. For the intermittent type of apparatus, the optimum operating conditions—those at which the yield of carbon per kilowatt-hour input reaches a maximum—were at a flow of about 6 amperes in the primary circuit, and an input of about 41 kilowatt hours per pound of carbon recovered. (See curve 2, Fig. 4.)

EXPERIMENTS WITH CONTINUOUS-TYPE APPARATUS.

The greatest difficulty met in the operation of a high-voltage electrical-arc process for making carbon black from natural gas is due to the "shorting" of the electrodes and lead-in tubes by the fluffy carbon deposited. In an attempt to overcome this deposition, a number of mechanically operated types of apparatus were designed, but without satisfactory results. The design shown in Figure 5, however, utilized a water or oil wash. It worked satisfactorily, and its continuous operation gave little difficulty.

This apparatus consists of an upper electrode and gas inlet, provided with a spreader or umbrella; a pyrex glass-tube reaction chamber; a lower electrode; a suitable drain for the wash solution;

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overflow cups; and a settling tank. Two buzzers kept the electrodes free from carbon "trees."

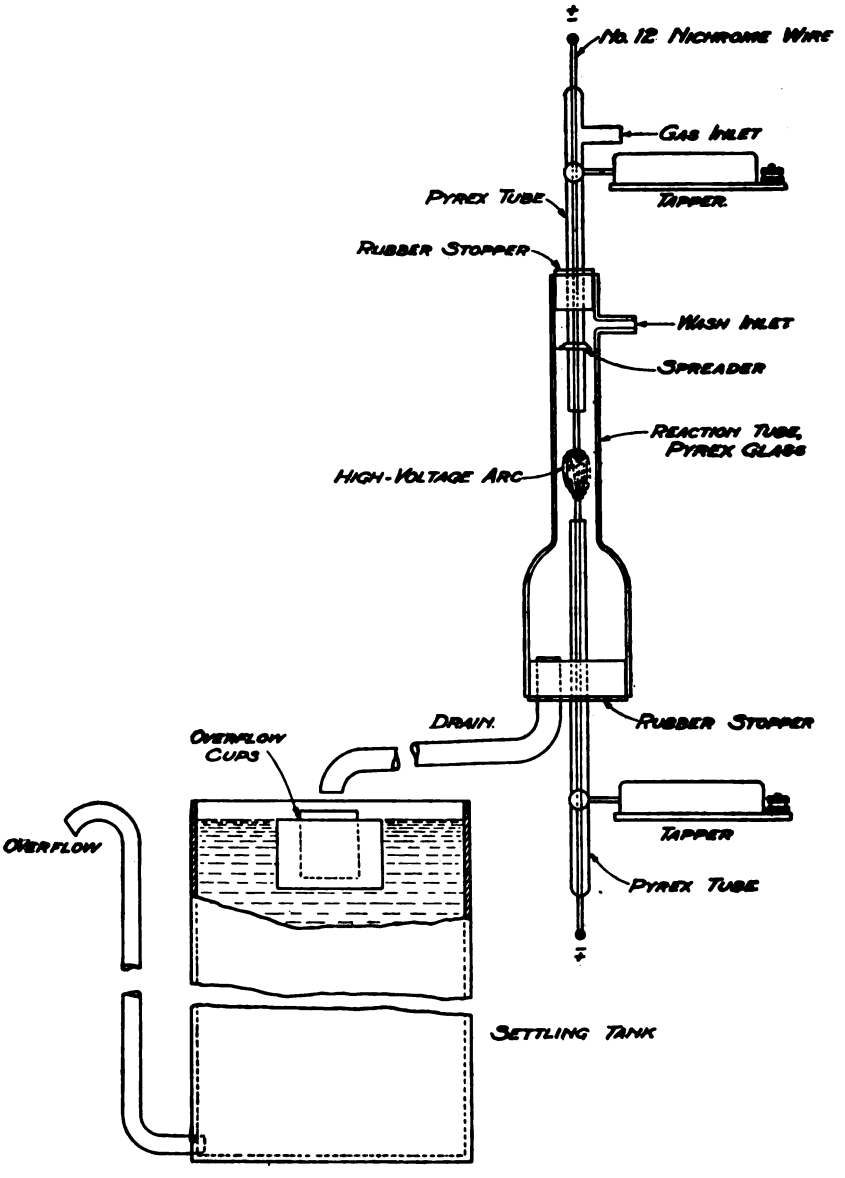

FIGURE 5.—Continuous-type laboratory apparatus for treating gas.

METHOD OF OPERATION.

The natural gas entered the apparatus through a side inlet tube in the upper electrode and flowed in the annular space between the nichrome electrode and the inside of the lead-in tube. After ex-

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posure to the arc, the residual gas left the apparatus through the drain, where it was thoroughly scrubbed to remove floating particles of carbon. Being finely divided, the carbon black is removed from the exit gases with difficulty. The drain-pipe should be long enough and have the smallest practicable diameter in order to insure thorough scrubbing of the exit gases. If the diameter of the drain-pipe is too large, the wash solution flows in the lower part of the pipe while the exit gases "channel" in the upper part, and thus carry out considerable carbon.

The oil or water wash-solution entered the upper part of the reaction chamber above the spreader or umbrella, which was a circular plate about one-eighth inch smaller in diameter than the inside of the chamber. Surface tension causes the wash solution to flow down the inner side of the chamber and form a liquid coating or wall upon which the carbon formed in the arc is deposited. Thus the carbon is washed out as fast as deposited, and the difficulties due to the building up of carbon deposits are avoided.

In the intermittent type of apparatus, the lead-in tube on the upper electrode projected beyond the end of the electrode in order to cause as much of the gas as possible to pass through the arc. In the continuous type of apparatus, the lead-in tube is shorter than the electrode, and the incoming gas completely fills the upper part of the reaction chamber. When oil—or comparatively pure water which has a low conductivity—is used as a wash, the diameter of the reaction chamber may be made so small that the arc almost completely fills the space inside the downward flowing wash, and in this way the gas is forced to pass through the arc.

RECOVERY OF CARBON FROM WASH SOLUTION.

The wash solution, with its collected carbon, drains to the settling tank after passing through a series of overflow cups to prevent agitation of the solution in the tank.

If water is used as a wash solution the carbon, possibly on account of its coating of gum formed from the polymerized reaction products of the arc, floats to the surface and collects as a thick scum, which may be skimmed off the water and dried in a drying oven at about 105° C. When dry the scum is very easily broken, with a brush, into a finely divided carbon black.

When the wash solution is oil, the carbon gradually settles out and collects in the bottom of the tank. The oil and carbon may be separated by any one of a number of methods, but the following procedure was followed in the laboratory: After the solution in the settling tank had stood 24 hours, the clear wash oil was siphoned off.

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The carbon and oil sludge left in the tank was washed with light gasoline (end point, 160° C.) to remove the heavy wash oil and any gums in the carbon. Then the mixture was filtered, the carbon remaining on the filter paper was dried at ordinary room temperatures, and the carbon "lumps" were removed and easily broken or disintegrated into their finely divided components. Drying the oil-carbon sludge from the settling tank without first washing with solvent gasoline proved unsatisfactory. The heavy oil and residual gums remaining in the carbon, even after filtration, required a comparatively high temperature (300° to 400° C.) for complete removal, and the resultant carbon was hard and contained many gritty particles. The heavy oil and the gums apparently act as a "binder" for the carbon particles and the product is a hard "coke" instead of finely divided carbon.

It seems probable that both the original carbon-kerosene sludge recovered in this process and the sludge recovered from the oil process described later could be used in a number of industries, especially paint making. Present methods in the manufacture of paints and pigments require the mixing of the black with oil. It seems probable by centrifuging the carbon-kerosene sludge enough oil would be removed to leave a heavy paste, which would be advantageous in many ways and would be easier to mix than the dry carbon black now used. Methods for producing carbon-black pastes are described later. When oil is used as a wash solution, the efficiency of the apparatus is about 8 per cent higher than that of the intermittent-type apparatus.

OPERATING CHARACTERISTICS OF CONTINUOUS-TYPE APPARATUS.

The operating characteristics for the continuous apparatus are practically the same as for the intermittent apparatus. When water is used as the wash solution, however, the results are slightly lower per kilowatt-hour input, and also there is difficulty in obtaining a smooth operating curve. The presence of water vapor lowers the yield of carbon black produced per kilowatt-hour input of energy, and the exit gases from the apparatus contain more carbon monoxide and carbon dioxide, which indicates a reaction between the hydrocarbons and the dissociated water vapor. As a result the presence of water vapor lowers the efficiency of the apparatus 5 to 10 per cent.

EFFECTS OF ENRICHING THE GAS.

The Pittsburgh natural gas available for the investigations was a "dry" gas, and did not contain appreciable amounts of hydro-

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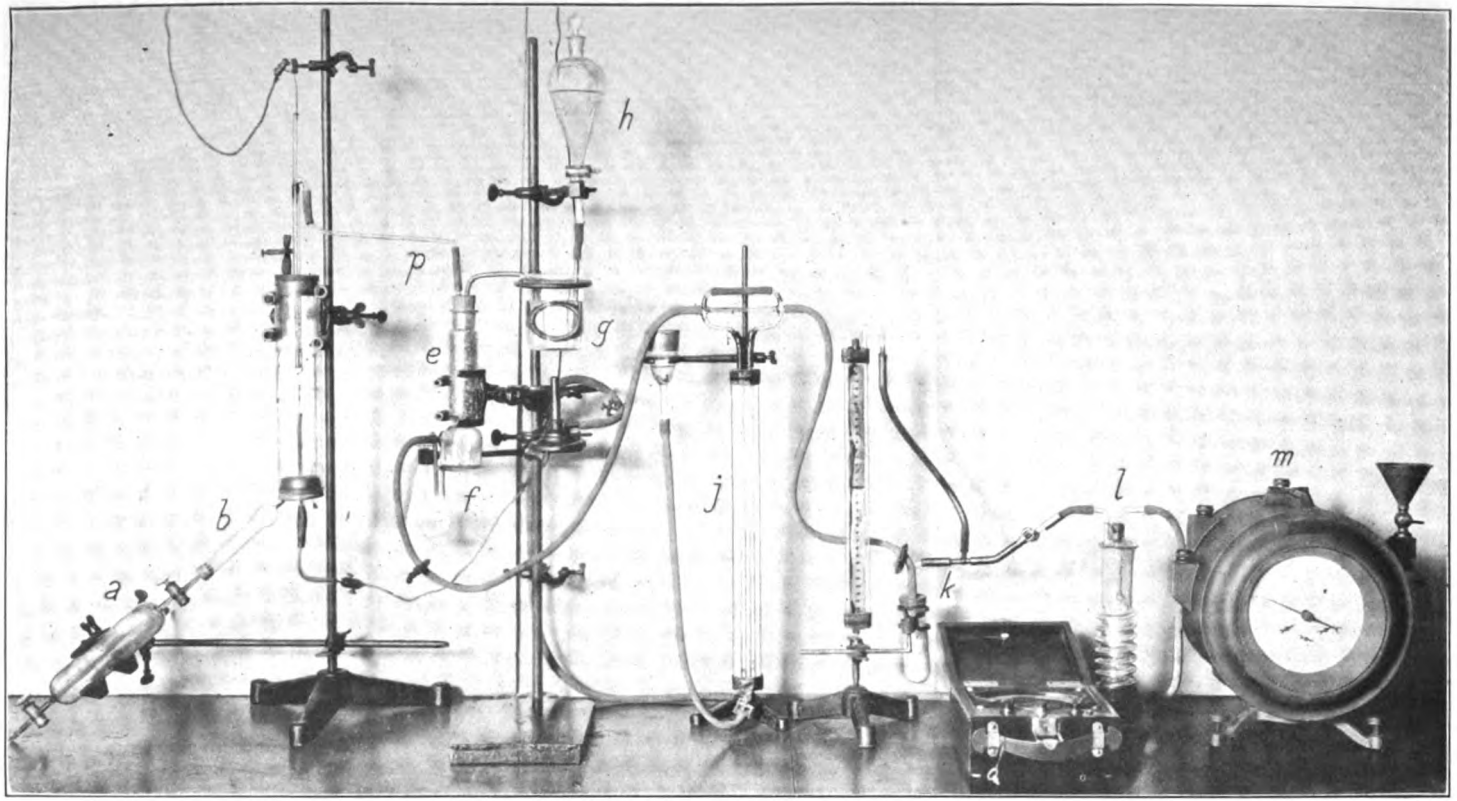

APPARATUS FOR STUDYING EFFECTS OF ENRICHING GAS, INTERMITTENT-TYPE TREATER

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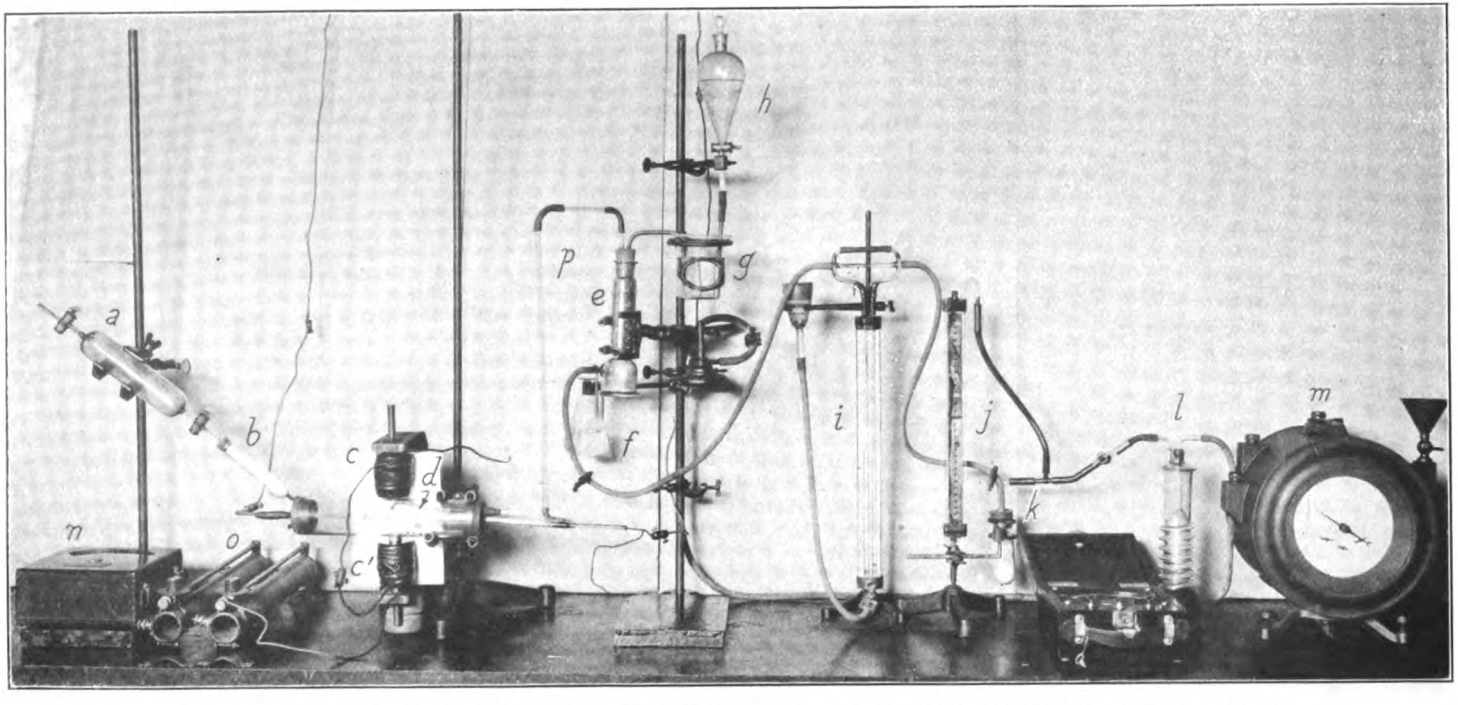

APPARATUS FOR STUDYING EFFECTS OF ENRICHING GAS, TREATER WITH MAGNETICALLY SPREAD ARC

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carbons higher than methane and ethane. In order to determine the effects of heavier hydrocarbons, the gas was mixed with the lighter vapors of gasoline. The apparatus used for these experiments is shown in Plates I and II.

The gas passed through the wet meter *m* (Pl. I), thence through scrubber *l*, containing concentrated sulphuric acid, and then through a glass-wool tube, *k*, to remove acid spray, then through the flow-meter *j*, and then to the bottom of the enriching tower *e*, where it passed upward through the glass beads into the tube *p* leading to the arc chamber. The enriching gasoline from the reservoir *h* flowed through the copper heating coil *g* immersed in hot water heated by a small Bunsen burner, and then into the top of the enriching tower and flowed downward, counter-current to the gas passing through the apparatus, into the receiver *f*. The gas obtained was very "rich" or "wet" gas, and its use gave a larger yield of black per kilowatt-hour input. In the assembly shown in Plate I an intermittent type of apparatus similar to that shown in Figure 3 (p. 10) was used. The gas leaving the treatment chamber passed a cotton filter, *b*, and then flowed through the gas sampling tube *a*.

Plate II shows an apparatus that was almost identical except for the use of a magnetically spread arc. The electromagnets *c* and *c'* were placed vertically, and the resultant vertical magnetic field distorted the arc into a horizontal flat circular sheet. The gas entered through the tube *d*, which was bent at the end, causing the gas to impinge on the flat arc almost perpendicularly. The remainder of the equipment shown in Plate II is the same as depicted in Plate I. Table 2 gives comparative runs for "dry" and "wet" gas with both types of apparatus.

Table 3 gives comparative runs for "dry" and heavily enriched gas for another type of apparatus, similar to that shown in Figure 3.

TABLE 2.—*Comparative runs for dry and wet gas in intermittent type and spread-arc type apparatus.*

	Primary current.	Power used.	Gas treated.[a]	Total carbon recovered.	Carbon per 1,000 cubic feet of gas.	Energy required per pound of carbon recovered.
	Amperes.	*Watt hours.*	*Cu. ft.*	*Grams.*	*Pounds.*	*Kw. h.*
Intermittent apparatus:						
Dry gas	6.8	155	0.460	1.43	6.85	50.0
Wet gas	6.85	148	.441	1.565	7.50	42.8
Spread-arc apparatus:						
Dry gas	6.85	200	.590	1.862	6.95	48.7
Wet gas	6.82	220	.630	2.21	7.74	42.0

[a] Increase in volume through enriching of gas not included.

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TABLE 3.—*Effects of enriching gas.*

Run No.	Condition of gas.	Flow of H_2O.	Gas used.	Time of run.	Flow of gas per minute.	Power used.	Total carbon recovered.	Carbon per 1,000 cubic feet of gas.	Power required per pound of carbon.
		Inches.	*Cu. ft.*	*Minutes.*	*Cu. ft.*	*Kw. h.*	*Pounds.*	*Pounds.*	*Kw. h.*
C83	Enriched	4.0	0.295	15.96	0.0183	0.676	1.507	11.26	54.1
84	Dry	4.0	.310	16.85	.01839	.676	.742	5.29	115.7
85	Enriched	4.0	.200	10.16	.0197	.676	1.057	11.64	49.15
86	do	2.5	.302	27.45	.0110	.676	2.142	15.65	66.4
87	do	7.5	.432	15.87	.0272	.676	1.810	9.24	44.6
88	Dry	7.5	.206	7.36	.0280	.676	.435	4.65	86.6
89	do	(a)							
90	do	2.5	.104	9.04	.0115	.676	.387	8.20	119.5

[a] Tube broke, run not completed.

MISCELLANEOUS EQUIPMENT.

DISCHARGE PASSING THROUGH DISKS.

In a few experiments the gas and the arc were passed through holes in mica or transite disks. One form of apparatus used was a 2-inch pyrex tube fitted with two mica disks spaced about 1 inch apart. Each disk had a central opening that was in line with the axes of the electrodes about one-half inch from the nearer electrode. The arc passed through these holes, as did the gas which entered at one end of the pyrex tube and flowed out of the other. The purpose of the disks was to bring the gas into the arc. Enough amperage was used to make the spark "fat" and completely fill the holes in the disks. Decomposition of the natural gas was almost complete, and most of the carbon formed when the gas passed through the hole in the first disk. Because of the high voltage necessary, the yield of carbon per kilowatt hour was not as large as that obtained in experiments with the apparatus described on page 10, and there was considerable trouble from deposits of carbon shorting the electrodes.

EFFECTS OF PRESSURE.

The effects of pressure on the energy required to decompose the gas have not been determined for any one type of apparatus. The data available are fragmentary, but seem to indicate that the energy required tends to vary inversely with the pressure. In one series of runs, with a decreased pressure of 183–184 mm. of mercury, the energy consumption ranged from 48.4 to 132.2 kw.h. per pound of black. At atmospheric pressure the minimum power consumption per pound of black—in any one type of apparatus this figure varies with the rate of flow—ranged from 40.5 to 41.8 kw.h.

Diminished pressure, according to Le Chatelier's theorem, should prove beneficial in promoting the decomposition of natural gas be-

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cause of the increase in volume from dissociation. For example, in the decomposition of methane ($CH_4=2H_2+C$), 1 volume of methane yields 2 volumes of hydrogen. The apparently great increase of efficiency in runs at atmospheric pressure seems to indicate, however, that through mass action the concentration may have an effect greater than that produced by changes of volume. The increased losses per pound of gas treated at the lower pressure may be caused by radiation, for the radiation from the arc is continuous, but the number of pounds of gas treated in a given time is less at the lower pressures.

No experiments have been made to determine in detail the effects of pressure in any one type of apparatus. The conclusions drawn here are based on rather quantitative results from different types of apparatus, and hence the values given above may vary considerably—as much from differences in apparatus as from the effects of different pressures.

EXPERIMENTS WITH REDUCED PRESSURE.

In order to get a more intimate "mixture" of the electrical arc or discharge and the gas, the pressure was reduced until the gas itself could be easily ionized and become the conducting medium. Different pressures and voltages were tried, but the results indicated that much of the energy was lost by radiation, and the carbon yield per kilowatt hour was considerably less than at atmospheric pressure.

PRECIPITATING CARBON PARTICLES FROM FLAME.

A few experiments were performed in an effort to ascertain whether the yield of present carbon-black plants, in which the carbon is made by the incomplete combustion of gas, could be increased by use of a device similar to the Cottrell precipitator to "throw out" the particles of incandescent carbon from the flame of the burning gas.

A luminous-flame burner was surrounded with a 1½-inch tube to serve as the outer electrode, and provided with an insulated central wire as the other electrode. Carbon was deposited on the walls of the tube, but it was difficult to keep the current from "blowing out" the flame. In every trial the flame could be extinguished by using a high enough voltage. Sixty-cycle alternating current and rectified Kenetron current at voltages ranging from 1,000 to 10,000 were used, but accurate quantitative runs could not be made because of the unsteadiness of the flame under the high voltages. The data obtained, however, seemed to indicate that the carbon yield per 1,000 cubic feet of gas was not appreciably higher than in present plants.

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EFFECTS OF HIGH-FREQUENCY CURRENT.

A high-frequency discharge or arc does not decompose natural gas into free carbon. The intermittent-type apparatus was used, but in no test did the high-frequency discharge produce carbon black. The high-frequency arc was obtained by shunting an adjustable (0.0005 to 0.0500 microfarad) glass-plate oil-immersed condenser directly across the electrodes without any additional inductance in the circuit. High radio-frequencies were used. The arc was very hot, and as measured by an optical pyrometer was hotter than the low-frequency arc; its temperature varied with the frequency and the current flowing, but ranged from about 2,000° to 3,000° F., whereas the temperature of the 60-cycle high-voltage arc was from about 1,500° to about 2,000° F. The experiments seem to indicate that the decomposition of natural gas by a high-voltage arc is not purely a heat reaction.

EXPERIMENTS WITH LOW-VOLTAGE, HIGH-AMPERAGE ARC.

A few experiments were tried with a low-voltage (110 and 220 volt, a. c. and d. c.) arc, but the quality of the carbon recovered was decidedly inferior to that recovered from the high-voltage arc. In color and in many other physical properties the carbon seemed to resemble lampblack or carbon produced by the thermal decomposition of natural gas—that is, by passing the gas through hot tubes or brick checkerwork. The carbon from the low-voltage arc also contained many hard crystalline particles, and had a gray color like that of graphite. The temperature of the low-voltage, high-amperage arc apparently was somewhat higher than that at which good quality carbon black can be formed. The electrodes volatilize and the carbon recovered contains a large proportion of this volatilized material.

USE OF OIL TO KEEP GAS WITHIN ARC.

In all the experiments on the electrical manufacture of carbon black from natural gas, the greatest difficulty lay in keeping the gas in close contact with the arc. An apparatus was therefore designed wherein transformer oil surrounded the arc. The two electrodes were placed vertically one above the other, and immersed in the oil. The lower electrode was hollow and served as a gas inlet. The gas flowed in rapidly, and there was little difficulty in keeping the arc going. The efficiency obtained was considerably better than that of other types of gas apparatus, and was apparently due to one or both of two factors—better contact between arc and gas, or decomposition of some of the oil surrounding the arc.

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PRODUCTION OF BLACK DIRECTLY FROM THE OIL.

Another run was made in which the gas was turned off as soon as the arc formed. With the electrodes separated only about one-sixteenth of an inch little difficulty was had in keeping the arc going. Carbon "trees" soon built out from each electrode and short-circuited the gap, but enough carbon was produced to indicate that the efficiency of the apparatus was considerably higher than when gas was used. Accordingly the author decided to investigate the direct manufacture of carbon black from liquid hydrocarbons.

PRELIMINARY EXPERIMENTS ON THE PRODUCTION OF CARBON BLACK FROM LIQUID HYDROCARBONS.

ELECTRICAL APPARATUS AND MEASUREMENTS.

In the experiments with liquid hydrocarbons practically the same electrical apparatus was used and was arranged in the same way, as in the natural gas experiments (see Fig. 1, p. 6); lower voltages and higher amperages could be used with oil.

METAL-TYPE ELECTRODES.

EFFECTS OF METAL ELECTRODES.

One of the first types of electrodes tried was heavy chromel A wire. At first the electrodes were arranged horizontally in the oil, but later they were placed vertically in an apparatus similar to that shown in Figure 3 (p. 10). When the flow of current in the secondary circuit was not enough to cause appreciable volatilization of the electrodes, carbon trees built out from the electrodes and soon short-circuited the arc. When the current flow was increased enough to cause volatilization of the electrodes, practically no carbon collected on or built out from the electrodes, but the electrodes themselves wore down almost proportionately to the current flow.

An interesting reaction took place when metal electrodes were used. The treated oil was filtered to remove the carbon black, and after the filtered oil had stood for about a week a precipitate settled out. This precipitate, a brown sludge, was at first thought to consist of polymerized products formed from the unsaturated hydrocarbons produced during the cracking reaction in the presence of the moisture in the original oil. To verify this supposition the kerosene was first treated with anhydrous aluminum chloride to remove the moisture and original unsaturated hydrocarbons, and then treated with sodium calcium hydrate to remove any hydrochloric acid resulting from the aluminum chloride treatment. When this treated oil was used in the apparatus and filtered to separate the carbon black, the same precipi-

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tate formed after the oil had stood for a week. Chemical analysis showed that the precipitate consisted largely of nickel and chromium acetylides, in somewhat the same proportion as in the electrode wire—85 per cent nickel and 15 per cent chromium. The weight of this brown precipitate was almost that of the carbon black formed, and the tinting strength of the black was reduced accordingly.

CARBON-TYPE ELECTRODES.

OPERATING CHARACTERISTICS OF STATIONARY CARBON ELECTRODES.

When carbon electrodes were tried only a slight trace of precipitate formed, not enough for analysis, and it is probable that the trace so formed may have been due to slight traces of metallic compounds in the electrodes themselves, or to the formation of gums due to polymerized products in the oil.

Only a few runs were necessary to show that for any fixed secondary voltage and current flow, the maximum efficiency of the apparatus was obtained when the electrodes were separated as far as possible without allowing the oil to quench the spark. In other words, cracking or decomposition of the oil seems to reach a maximum when the most arc surface is exposed to the oil. It is probable that the decomposition is confined to the thin layer immediately surrounding the arc, and as the temperature gradient between the arc and the oil is very steep, the actual thickness of this layer is not much more than a fraction of a millimeter.

The oil breaks down into elemental carbon, hydrogen, some methane, and, depending on the type of oil treated, arc temperature, and other conditions, into considerable quantities of light unsaturated gases. If the arc is drawn out too much, and too large an area is exposed to the cooling action of the surrounding oil, the ionization of the arc gases decreases and the arc resistance increases rapidly, with a resultant quenching of the arc. The decomposition of the oil seems to be largely, perhaps entirely, due to thermal dissociation by the high temperatures of the arc; if this is so, the maximum efficiency of the apparatus in recovering carbon black will be reached when the maximum amount of electrical energy is used in the arc itself for directly dissociating the oil into its elemental constituents.

As the high voltage used requires a large number of turns of wire on the transformer secondary when power is taken from a low-voltage source, there may be appreciable losses in the windings of the transformer. The energy dissipated in the total secondary circuit is largely made up of the sum of the energy dissipated in the total copper circuit and in the arc itself. The resistance of a short arc is comparatively small; therefore it is desirable to keep the resistance of the gap as high as possible, in order that the heating

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(I^2R) losses of the gap may be as large a proportion as possible of the total I^2R losses of the entire circuit. This can, of course, be done in practice only by keeping the gap as long as possible (or by distorting the arc as by magnetic spreading, etc.) in order to allow the desired amount of current to flow.

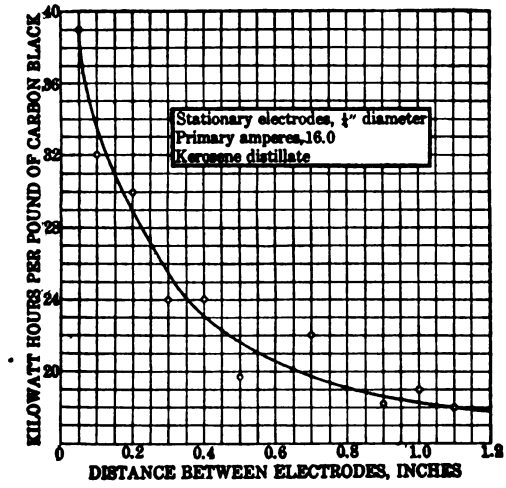

FIGURE 6.—Stationary electrodes operating curve.

EFFECTS OF GAP LENGTHS WITH STATIONARY CARBON ELECTRODES.

In order to investigate the effects of gap lengths, experiments were run in which the amount of current and wattage flowing through the circuit were kept as nearly constant as possible and the distance between electrodes varied. The data in Table 4 and the curve of Figure 6 give the results of these runs.

TABLE 4.—*Results with treater having one-fourth-inch stationary carbon electrodes (primary amperes, 16).*

Run No.	Gap length (after starting arc).	Primary electrical current.	Carbon.	Power used.	Power used per pound of carbon.
	In.	*Amperes.*	*Grams.*	*Kw. h.*	*Kw. h.*
C139	0.05	16.7	4.612	0.36	39.10
140	.10	16.2	4.67	.33	32.00
141	.20	16.7	6.04	.40	30.00
142	.30	16.0	13.88	.73	23.95
143	.40	16.4	10.21	.54	24.00
144	.50	15.9	8.97	.39	19.70
145	.60	16.3	9.42	.58	27.93
146	.70	16.3	14.33	.59	22.00
147	.80	16.2	Meter stuck.		
148	.90	16.3	20.06	0.83	18.30
149	1.00	16.5	20.12	.84	19.01
150	1.10	16.5	8.61	.34	18.00
151	1.10	16.3	(Arc quenches out.)		

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It will be noticed that the maximum efficiency—that is, the lowest number of kilowatt hours per pound of black—would seemingly be obtained at maximum arc length; for then the proportion of the total energy of the circuit dissipated in the arc as heat would be greatest, and the area of contact between oil and arc would reach a maximum.

In this series of runs the vertical electrodes used were of ¼-inch arc-light carbons. The assembly of the apparatus was similar to that of Figure 3, except that the upper electrode was mounted on a movable rod whereby it could be "struck" or brought within breakdown distance of the lower electrode in order to start the arc. By measurement, the dielectric strength of the oil was found to be about 30,000 volts per 0.10 inch, and the arc was started by bringing the electrodes together. After the arc had started, the upper electrode was gradually raised until the distance between the electrodes was that desired. Considerable difficulty was met in maintaining a steady arc, and with the wider gaps very careful adjustment was necessary to prevent the arc being completely extinguished. As the electrodes gradually wore down continual feeding-in of electrodes was necessary.

ROTATING-TYPE ELECTRODES.

EFFECTS OF GAP LENGTHS WITH ROTATING ELECTRODES.

The experiments with the vertical electrodes indicated that the most efficient type of electrode would be one with which the gap could be kept as long as possible and maximum contact obtained between arc and oil. The ideal gap is one in which the gap length decreases automatically within breakdown distance immediately on the quenching of the arc.

The rotating-electrode gap, one of the types tested, fulfilled the above conditions fairly well. This type of gap is shown in Plate III and in Figure 7. The electrodes were two 1½-inch carbon disks, one-fourth inch thick; they rotated in opposite directions; hence adjacent points on the peripheries of the two disks at a line joining their centers traveled in the same direction. The center-line distance between the peripheries was small enough for the voltage used during the run to start an arc through the oil.

As soon as the arc starts, the spark travels, or rather drifts, aided by the mechanical carrying of the swiftly flowing oil between the rotating disks, and the arc lengthens. The arc is drawn out until its resistance increases to a point greater than that of the breakdown voltage required to puncture the oil between the disks; then it immediately starts again at the center line of the disks. This type of gap keeps the arc spread out, continually forces a new supply of oil into it, and is one of the most efficient tried so far. Rotation of the

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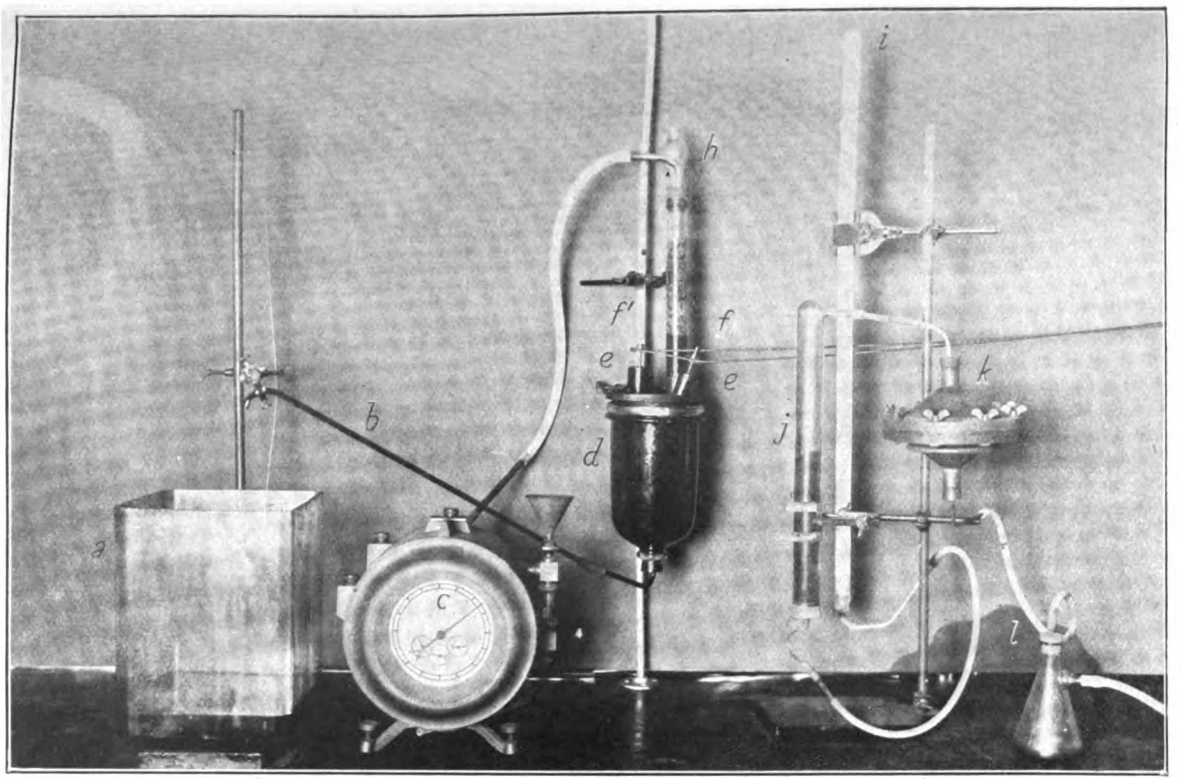

LABORATORY APPARATUS FOR OIL PROCESS

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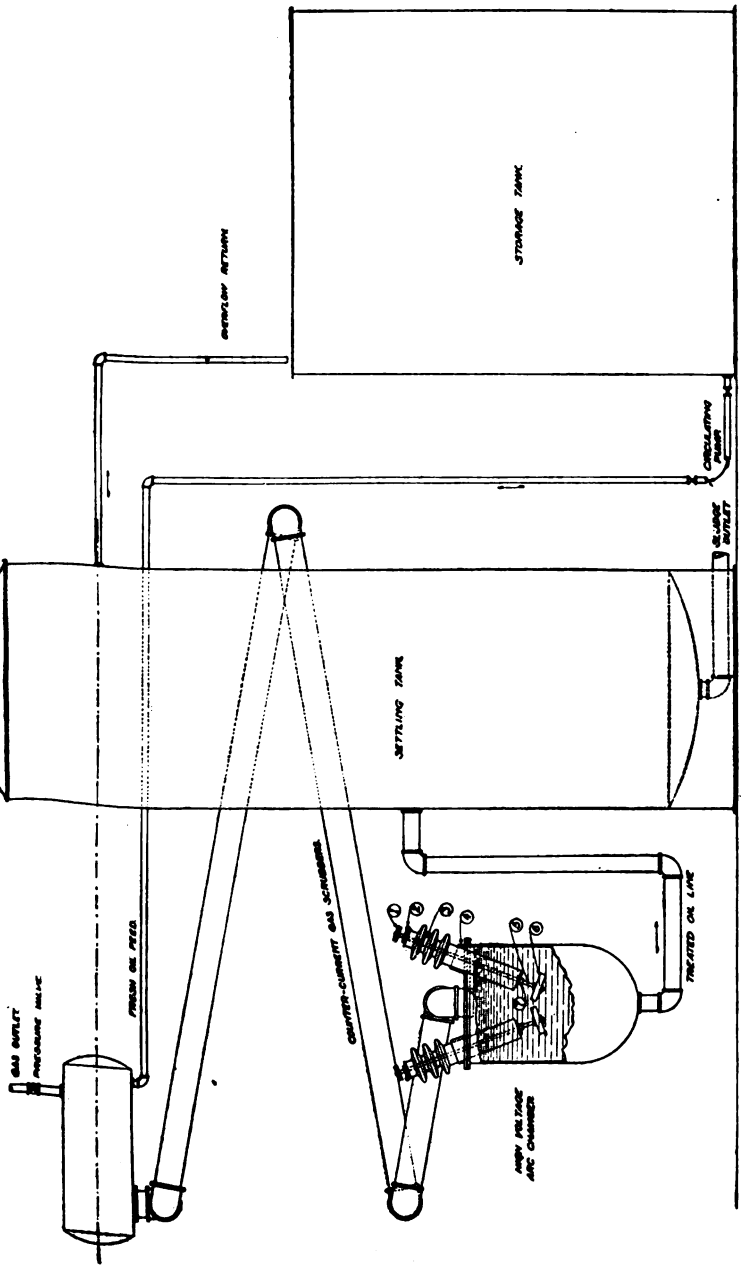

FIGURE 7.—Proposed semi-industrial equipment for continuous high-voltage carbon-black process.

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disks prevents "hot spots" where the arc forms. The volatilization of the disks is not appreciable, but the disks wear away slightly by reason of the mechanical breaking or chipping away of the carbon particles on their peripheries. The center-line distance between the peripheries of the disks should be as large as possible, and yet so close that the arc, after quenching, will immediately start without an appreciable time interval.

OPERATING CHARACTERISTICS OF TREATER WITH ROTATING ELECTRODE.

Calculation of the exact distribution of energy in the total system of the rotating-electrode treater is difficult because of so many side reactions, such as formation of methane, ethane, and unsaturated gases, during the decomposition of the oil. Calculations based on present available data indicate that the electrical losses in the secondary of the transformer circuit, in the connecting leads, and in heating metal are probably not much more than 5 to 15 per cent of the total energy used in the system. On this basis about 90 per cent of the total energy supplied is dissipated either in the form of radiant energy or heat, or is utilized by the endothermic side reactions going on simultaneously with the decomposition of the oil. A major portion of the energy is utilized in the side reactions, yet because the radiation losses are relatively high it seems probable that increasing the amount of current through the apparatus will increase the efficiency. Under certain electrode conditions a very small flow of current produces very little carbon black. It seems a certain temperature must be reached in the arc before the decomposition becomes appreciable, and it is conceivable that all current supplied while the arc is below this "critical" temperature will be useless in producing carbon black. Increasing the amperage above this critical point increases the production of black per kilowatt-hour input.

The efficiency of the apparatus varies greatly with the type and characteristics of the oil treated. The lighter and more volatile the oil, the greater is the power input required per pound of black, possibly because the molecular structure of volatile oils is less complex. In the ordinary thermal cracking of hydrocarbons those with the less complex molecular structures are, it is generally believed, much more difficult to decompose than those of more complex structure. Also, it seems highly probable because of the high temperatures in the arc, that the volatility of the oil is of much importance. When a volatile oil such as 70° A. P. I. gasoline is treated, the efficiency of the apparatus is almost as low as when natural gas is treated, possibly because the gasoline surrounding the arc is so easily volatilized that the arc comes into contact with vapors only.

The effects of pressure have not been studied, but increased pressure would insure better contact between oil and arc, which would

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probably result in a higher over-all efficiency if the increased pressure did not too greatly increase the quenching of the arc. Each type of oil will probably require a different pressure for optimum operating conditions, and the more volatile the oil, the greater the pressure required in order to keep it in contact with the arc. Since the energy lost through radiation, through endothermic gas reactions, and in other ways is many times greater than that required for actually decomposing the oil, it is essential to have the maximum mass of oil molecules in contact with the arc, and this can only be accomplished by keeping the oil in the liquid state.

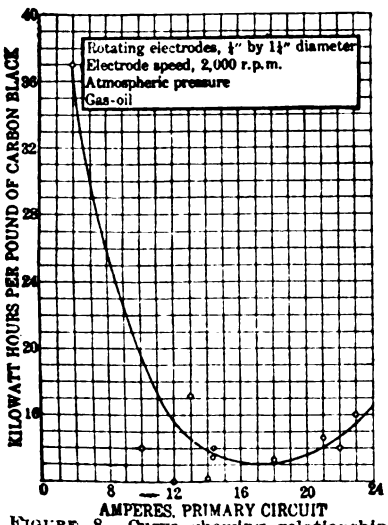

FIGURE 8.—Curve showing relationship between primary amperes and kilowatt hours per pound of carbon black.

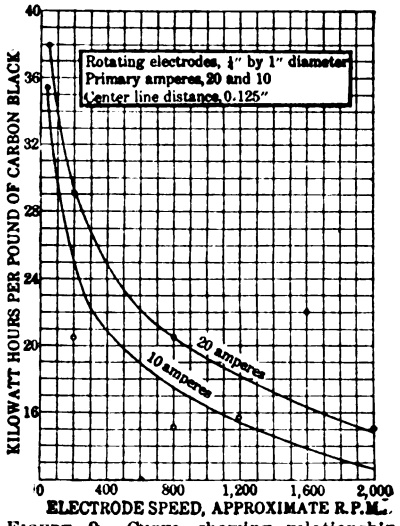

FIGURE 9.—Curve showing relationship between electrode speed and kilowatt hours per pound of carbon black.

TABLE 5.—*Relationship between primary amperes and kilowatt hours per pound of black.*

Run number.	Energy used.	Primary current, average.	Carbon recovered.	Energy required per pound of carbon.
	Kw. h.	*Amperes.*	*Grams.*	*Kw. h.*
C117	0.30	14.5	10.00	13.6
120	.49	13.0	13.00	17.2
121	.40	14.0	15.10	12.2
123	1.10	14.5	Electric meter stuck.	
123a	.86	14.5		14.0
124	.92	12.0	34.80	12.0
125	3.58	18.0	122.60	13.25
131	1.72	22.0	55.75	14.0
132	.92	21.0	28.42	14.7
133	1.25	23.0	35.5	16.0
134	1.62	13.0	Electric meter stuck.	
135	.87	10.0	28.2	14.0
136	.93	16.0	Electric meter stuck.	
137	1.31	6.0	35.0	37.0

Transformer (primary, 80 turns, and secondary, 8,000 turns). Transformation ratio, 1 to 100.

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The curve of Figure 8, derived from Table 5, shows the apparent relation between primary amperes and kilowatt hours per pound of black recovered at constant electrode speeds. During these runs the gap distance and speed of electrodes were kept as constant as possible, the only intended variable being the primary current. The reader will note that the efficiency of the apparatus increases up to a certain amperage and then begins to decline. This would seem to indicate a relation between current flow and arc area exposed to the oil—the greater the current flowing in the circuit the more the arc must be distorted in order to allow the apparatus to operate at its maximum efficiency.

RELATION BETWEEN ELECTRODE SPEED AND POWER INPUT PER POUND OF BLACK RECOVERED.

The increase in efficiency due to increase in arc distortion or exposed arc surface is shown in Figure 9, and by Table 6.

TABLE 6.—*Relationship between electrode speed and kilowatt hours per pound of black.*

Run No.	Electrode speed, approximate.	Primary current average.	Carbon recovered.	Energy used.	Energy used per pound of carbon.
	R. p. m.	*Amperes.*	*Grams.*	*Kw. h.*	*Kw. h.*
C 156	40	20.2	5.6	0.46	37.1
157	800	20.0	5.9	.49	20.6
158	200	19.7	9.1	.58	29.0
159	1,600	20.2	10.4	.51	22.1
160	2,000	20.3	17.0	.57	15.2
C 161	40	10.0	7.4	.58	35.5
162	200	9.8	11.1	.50	20.5
163	800	10.2	13.4	.45	15.2
164	1,200	10.0	20.5	.71	15.7
165	1,600	10.4	22.9	.80	15.8

In this series of two sets of runs the primary amperage (10 amps. and 20 amps.) and the linear distance between electrodes were kept constant and the rotation of the electrodes was varied. The electrodes were graphite disks one-fourth inch thick and about 1 inch in diameter, and the minimum distance between their peripheries was one-eighth inch. The similarity between the curves in Figure 9 and that in Figure 6 indicates that the highest efficiency of the apparatus will be secured when the maximum amount of arc surface is exposed to the oil. These curves also show that the greater the current flow the greater should be the distortion and the higher will be the arc speed of rotation required to keep the efficiencies equal.

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GENERAL LABORATORY APPARATUS.

Plate III (p. 24) shows the general laboratory apparatus used in these investigations, and that in Figure 7, page 25, shows apparatus proposed for larger scale tests.[5] This apparatus is patterned after the present laboratory equipment. The principle of operation remains the same. In the laboratory apparatus (Pl. III) the oil was placed in the reservoir *h*, and flowed by gravity through the glass bead scrubber and into the treating chamber *d*, where it was exposed to the high-voltage arc. From the treating chamber the oil and carbon black flowed through the tube *b* to the settling tank *a*, where the black gradually settled out; the clear oil was siphoned off and again placed in reservoir *h* to repeat its cycle of operation. The gas coming from the treater passed upward through the scrubber and then through the meter *c* into the atmosphere.

In the proposed apparatus shown in Figure 7 the oil would be placed in a suitable storage tank and then passed through a circulating pump to a header at the top of the counter-current gas scrubbers. From the header the oil would flow down through the scrubbers into the treating chamber. After passing through the arc or treating chamber the treated oil would flow to a settling tank. In the settling tank the clear oil would gradually rise to the top and pass out through an overflow either back to the original storage tank or to stills for redistillation. The carbon from the settling tank could be drawn out near the bottom in the form of a sludge and then treated as described later, page 32. The gas produced during the decomposition of the oil in the arc chamber would be passed through the scrubber, counter current to the incoming oil, and out of the gas outlet at the top of the header. This gas coming from the arc chamber contains a large amount of carbon in suspension, and it was found that thorough scrubbing was necessary in order to remove it. In order to aid the scrubbing process it may be beneficial to have the entire system under pressure, in which case the pressure valve at the top of the header could be set for any value. The effects of pressure upon the carbon formation are not known, but, as previously mentioned, it seems probable that a high pressure would tend to keep the oil in closer contact with the arc, prevent much volatilization of the oil, and thereby insure higher efficiency.

ARC CHAMBER.

The arc chamber of the laboratory apparatus was a bell jar with a cover held on by thumb bolts. The rotating electrodes *f* and *f*[1]

[5] Process and apparatus patents have been applied for by the author.

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(Plate III) entered through the lid of the apparatus through large insulating bushings *e* and *e*. The construction of the treater is better shown in Figure 7 (p. 25). In this proposed apparatus the electrodes enter through the cover of the treater through large insulating bushings, 3. The electrodes, 6, which in the laboratory apparatus were 1¼ inches in diameter and one-fourth inch thick, are mounted on the shaft, 5, which passes through the stuffing box, 7. At the top end of the shaft is a pulley, 1, and a brush contact, 2, for connection with the power supply. For rotating the electrodes in the laboratory apparatus, a small motor was used with a round leather belt that was long enough to prevent leakage of current across it between the two electrodes.

OILS USED AND SUITABLE FOR PROCESS.

The experiments so far have been confined largely to treating kerosene or gas oil, as these are easy to work with and the results may be watched a little more closely than when heavier oils are used. However, a few runs have been made with gasoline, naphtha, benzol, creosote, alcohol, pine-tar oil, fuel oil, and transformer oil. A satisfactory grade of black was made from each of these oils, and also from alcohol, although the power requirements per pound of black recovered varied with the type of oil being treated.

Oxygen compounds, such as creosote, seem to break down more easily and to require less expenditure of power than the straight-run paraffin hydrocarbons; and it seems probable that some of the cheap creosote distillates or light hardwood oils may be used satisfactorily in regions where they are produced and where cheap petroleum distillates are not available. These compounds are unstable and break down easily and give high yields of carbon; but the main trouble seems to be that they tend to form pitch and "gummy" residues. The few experiments conducted on these oils do not justify the drawing of definite conclusions, although the results obtained were satisfactory enough to warrant further investigations if the production of carbon black by the electrical process is attempted on an industrial or even semi-industrial scale. When creosote or similar oils are used greater difficulty is experienced in washing or removing them from the black, and the increased cost of washing may offset their slightly cheaper cost as compared with petroleum oils. For certain pigment uses, however, the oxygen-compound oils may prove better than the same quantity of petroleum oils if the carbon is allowed to remain in the oil.

A distillation analysis of the kerosene used during a major part of the work appears in Table 7 and an analysis of the gas oil in Table 8.

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TABLE 7.—*Distillation analysis of kerosene.*

Specific gravity, 0.784.
Hempel column. 300 c. c. used. First drop: 145° C.

Temperature.	Vol., c. c.	Per cent.	Sum per cent.	Sp. gr.
190	23.6	7.9	7.9	0.774
195	10.0	3.3	11.2	.779
200	9.6	3.2	14.4	.780
205	16.2	5.4	19.8	.781
210	15.3	5.1	24.9	.783
215	16.0	5.3	30.2	.784
220	18.5	6.2	36.4	.786
225	22.7	7.6	44.0	.789
230	20.6	6.9	50.9	.791
235	23.0	7.7	58.6	.793
240	20.0	6.7	65.3	.795
245	19.0	6.3	71.6	.797
250	16.2	5.4	77.0	.800
255	15.4	5.1	82.1	.802
260	12.0	4.0	86.1	.806
265 270 275	27.6	9.2	95.3	.811

Average boiling point, 232.5° C.

TABLE 8.—*Analysis of gas oil (Sample No. 1075).*

Specific gravity, 0.829. A. P. I. gravity, 39.2°.
Air distillation, barometer, 733 mm. First drop: 146° C.

Temperature, ° C.	Per cent cut.	Sum per cent.	Specific gravity cut.	° A. P. I. cut.	Temperature, ° F.
Up to 200	2.5	2.5	0.787	48.3	Up to 392
200–225	4.3	6.8			392–437
225–250	11.9	18.7	.806	44.1	437–482
250–275	16.3	35.0	.818	41.5	482–527
Vacuum distillation at 40 mm.					
Up to 200	17.3	17.3	.830	39.0	Up to 392
200–225	23.9	41.2	.839	37.2	392–437
225–250	14.9	56.1	.848	35.4	437–482

EFFECT OF TREATMENT ON THE OILS.

Ordinary distillation analysis shows little difference between the original and the undecomposed treated oils. The color of the oil, however, becomes deep mahogany. When in suspension in the oil, even in considerable quantities, the finely divided carbon black has no appreciable effect upon the dielectric properties of the oil. The oil-carbon mixture does break down at a relatively low voltage, however, when enough carbon is present to form a "sludge." With the same percentage, by weight, of carbon present, the oxygen-compound oils lose their dielectric properties sooner than paraffin-base hydrocarbons. This difference may be due to the presence of water formed by the liberation of hydrogen and oxygen in the breaking down of oxygen-compound oils.

The deep mahogany color of the treated oil may be due to colloidal carbon. When the treated oil is evaporated to dryness, under conditions preventing decomposition, a small quantity of finely divided

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carbon remains in the flask. The distilled oil has practically the same color as before treatment by the arc.

The lower the viscosity of the oil treated the easier is the separation of the black from the oil after treatment. When heavy viscous oils are used there is considerable difficulty in removing the black; filtration is very slow and considerable washing with a light oil, such as 70° A. P. I. gasoline, is necessary to remove the heavy oil to prevent its acting as a "binder" and "coking" or agglomerating the finely divided black during drying.

The heavier, more viscous oils are usually cheaper than the lighter oils, such as kerosene distillate or gas oil, and it seems probable that in commercial operation an optimum point must be reached between cost of the original oil and the increased cost of removing the black from a more viscous oil. Present available data indicate that a suitable oil will be unrefined kerosene distillate, or an unrefined light cracked distillate such as that produced by cracking gas oil in Burton stills. This distillate, because of its high vapor pressure, is usually unsuitable for further cracking in the ordinary types of stills, and largely because of its high unsaturation is not considered highly suitable for refining or blending and marketing.

REMOVAL OF CARBON BLACK FROM THE OIL BY FILTRATION.

The carbon black suspended in the oil may be removed by a number of well-known filtering or drying methods. In the laboratory investigations the following procedure has been used: The treated oil is either allowed to stand long enough so that the black will separate out by gravity, or it is centrifuged. The clear oil is then decanted from the top of the mixture and the sludge filtered. The carbon is readily held by filter paper, and can be washed with a light solvent to remove the absorbed heavier oil. After two or three washings the carbon is dried in an oven for removal of the wash liquid, and is then ready for "pulverizing" and pneumatic separation. The carbon from the filter contains small traces of impurities, such as grit and metallic particles, a major proportion of which come from the electrodes. If a dry carbon black is being made, the grit and metallic particles are not particularly detrimental, as they are removed during the pneumatic separation. However, if a carbon-black "paste" is being made, considerable care must be taken to keep the oil clean, and electrodes should be used which will give off as few particles as possible.

PNEUMATIC SEPARATION OF THE BLACK.

The pulverized carbon black as made in these experiments contains particles of agglomerated black larger in size than is desirable or permissible for a good grade of carbon black, besides some particles

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of grit and electrode material which should be removed. In the early laboratory work the pneumatic separator at the right in Plate III (p. 24) was used, but later the apparatus shown diagrammatically in Figure 10.

The improved apparatus consists essentially of a drying tube filled with calcium chloride; a pneumatic separating chamber, having a side inlet tube, through which the pulverized black is fed into the

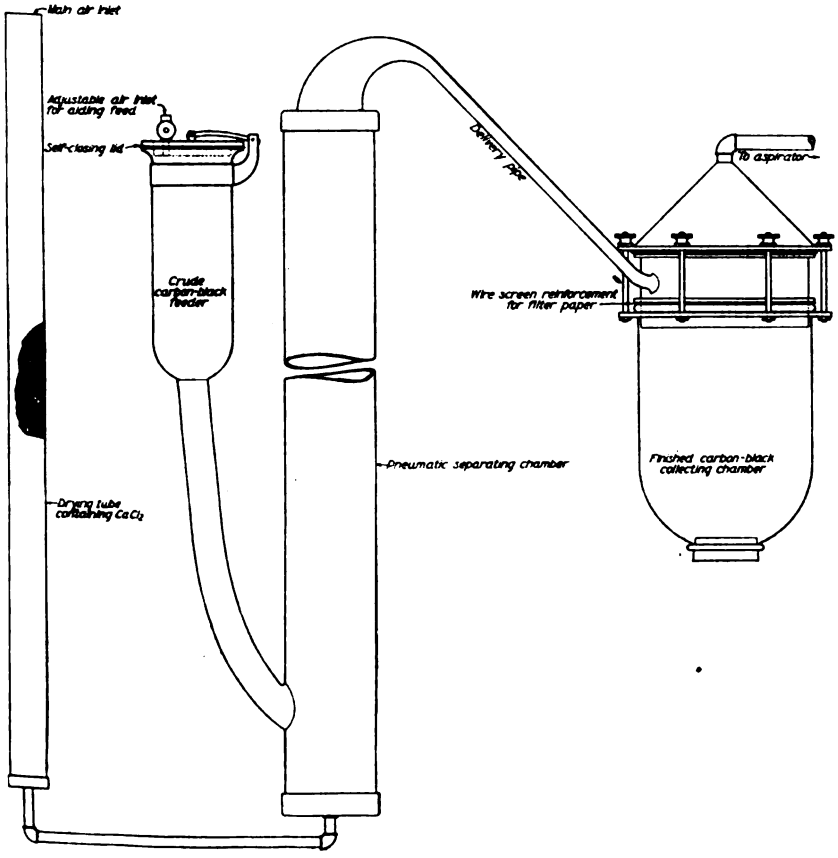

FIGURE 10.—Later and improved type of pneumatic separator for carbon black.

apparatus; and the separating or filtering chamber for collecting the carbon black.

The pulverized black is intermittently fed through the self-closing lid, at the top of the feed tube, and gradually settles to the bottom of the separating chamber. In order to prevent jamming or packing of the pulverized material in the feed tube, and also to aid uniform feeding of the pulverized black to the separating chamber, an adjustable air inlet valve is provided in the self-closing lid.

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The air is drawn through the apparatus by means of a small motor-driven suction pump. The air first passes through the drying tube for removal of moisture and then enters the bottom of the separating chamber. The finely divided carbon black is "floated" by the incoming air and carried upward to the top of the chamber and thence through the delivery pipe to the filtering chamber.

The filtering chamber consists essentially of a hood from which connection is made to the suction pump, a collar, and a glass bell jar. Between the hood and the collar is the filtering medium—a sheet of coarse filter paper reinforced by a wire screen placed on top of it—which effectively removes the suspended carbon black from the air. The black "builds up" on the bottom side of the filter paper, and when an appreciable thickness has accumulated it drops off into the bell jar. The black collected may be removed through the plug provided at the bottom of the bell jar after the suction has been stopped.

In order to obtain a better distribution of the black as it builds up on the filter, the delivery tube enters the collar in a somewhat tangential direction and thus gives the incoming air a cyclonic swirl. The grit and the larger agglomerated particles of black remaining in the bottom of the separating chamber are removed when a sufficient quantity has accumulated, are repulverized, and then again fed into the apparatus. The larger agglomerated particles are easily broken down, and do not require "grinding," as ordinarily meant, for their reduction. In the laboratory they were "mashed" with a large spatula on a glass plate.

For larger scale operations some of the standard pulverizing equipment now on the market would be desirable. A ball mill or similar grinding machine is not satisfactory because the agglomerated black has a tendency to build up when compacted. An impact pulverizer or machine of similar type in connection with a properly designed pneumatic separator would probably be satisfactory. To make the process continuous, the larger particles should be automatically returned to the mill for further treatment.

PROPERTIES OF ELECTRICALLY MADE BLACK.

A number of small-scale tests have been made to determine the approximate quality of the black and its general characteristics. In tinting strength the black compares favorably with the better grades of carbon black now on the market. The tinting strength was ascertained by mixing a given weight of pure white zinc oxide with a smaller given weight of carbon black, and comparing the resultant color with that obtained by the same weights of zinc oxide and carbon black of a known commercial standard. The zinc oxide and

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carbon black were ground into raw linseed oil for about 20 minutes with a glass muller on a glass plate. The tinting strength of the electric-process black and its high covering power indicate the fineness of its particles and its comparative freedom from volatile oils.

MICROSCOPIC EXAMINATION OF ELECTRICALLY MADE BLACK.

The ultimate particles of this carbon black are so minute that they exhibit colloidal properties. With ordinary magnification these ultimate particles can not be detected and the black appears as irregular agglomerates. To distinguish the particles ultramicroscopic methods are necessary. Therefore the black was examined at very high magnification—1,000 to 2,000 times—with a mono-objective binocular microscope equipped with an oil immersion lens and a dark field condenser, by which the extremely small particles of black become visible from the light they reflect. Although the particles themselves are black, this reflected light makes them appear as white particles upon a black background, as in the photomicrographs reproduced on Plates IV to VIII.

As these photomicrographs show, the average particles of electrically made carbon black appear to be considerably smaller than those of carbon black made by present methods. Two of the illustrations (Pls. VI, *a*, and VI, *b*) indicate that the electrically made black does not tend to form agglomerates. Plates VI, *a*, represents carbon black immediately after preparation of the slide, Plate VI, *b*, was photographed one week after the slide was prepared, but no agglomerate of carbon particles is visible, the particles being as finely divided and as widely separated as at first.

When in oil the electrical carbon black has different properties from ordinary carbon blacks—chiefly in that it does not tend to agglomerate after dispersion in the oil. It is somewhat harder to disperse than ordinary gas blacks, but, once in that state, it remains dispersed indefinitely. The difference was noticeable while slides of the blacks were being prepared for photomicrographs. Ordinary carbon or gas blacks were easily dispersed, but the rapid agglomeration of their ultimate particles gave trouble in preparing slides for photomicrographs; sometimes the agglomerating completely raised the cover glass on the slide.

Viewed under the microscope, the electrical black compares favorably with the better grades of carbon black now on the market. The particles are about 0.2 or less of a micron (1 micron=1/25,000 inch) average size. Plates IV to VIII, inclusive, show the relative sizes of particles of different carbon blacks and lampblacks and of electrical black produced by the electrical process. The larger particles shown in Plate VI were undispersed particles or lumps of the original material.

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CARBON-BLACK PIGMENT.

PRODUCTION OF CARBON BLACK IN ANY DESIRED BASE OIL.

When the carbon-black sludge from the settling tank is simply centrifuged to remove the excess oil, a small amount of the oil remains in the black. It is probable that the proportion of oil would not be high enough to prove detrimental for many uses, but for some specialized uses it would be. It is possible to remove this oil with a solvent and then dry the black as has been described.

As an alternative to such washing, and in order to obviate its necessary expense, the following method might be used; it has been tried in a small way and has yielded a good grade of carbon-black paste: In attempts to drive off all the oil by thermal distillation, the black agglomerated and formed a hard gritty "coke." To prevent this agglomeration, a little linseed oil was added to the carbon-black paste (which had been prepared from kerosene distillate) and the mixture distilled under a vacuum of 40 mm. The light oil used came off below 200° C., leaving the carbon black suspended in the linseed oil. The presence of the linseed oil kept the carbon black from agglomerating or coking, and it is believed this process can be developed for the production of a satisfactory carbon-black paste for use in practically all pigment and ink work. In slight variation of this process the original oil being treated was mixed with a small amount of linseed oil, and the mixture passed through the arc. The sludge produced by this run was then placed in a distillation flask and the excess hydrocarbon oil removed. This procedure, however, wastes that part of the linseed oil which is decomposed with the kerosene distillate or other oil being treated.

A carbon-black paste, whether in a base of linseed or other oil or containing a small percentage of the original oil, has advantages over a dry black for many uses, such as pigment mixing. The paste is easily handled, does not "fly," and may be shipped at a considerably lower rate than the dry fluffy black. A paste composed of carbon black and some oil or solvent not detrimental to rubber may possibly find use in rubber compounding. Many such combinations are possible, and future experiments will doubtless bring out such products.

Pine-tar oils are easily decomposed in the arc, but by direct treatment the quantity of black in the treated oil can not be made greater than 10 to 15 per cent without shorting of the electrodes. However, a batch of the oil can be treated, the untreated oil distilled off, and the black left in a small percentage of the undistilled oil.

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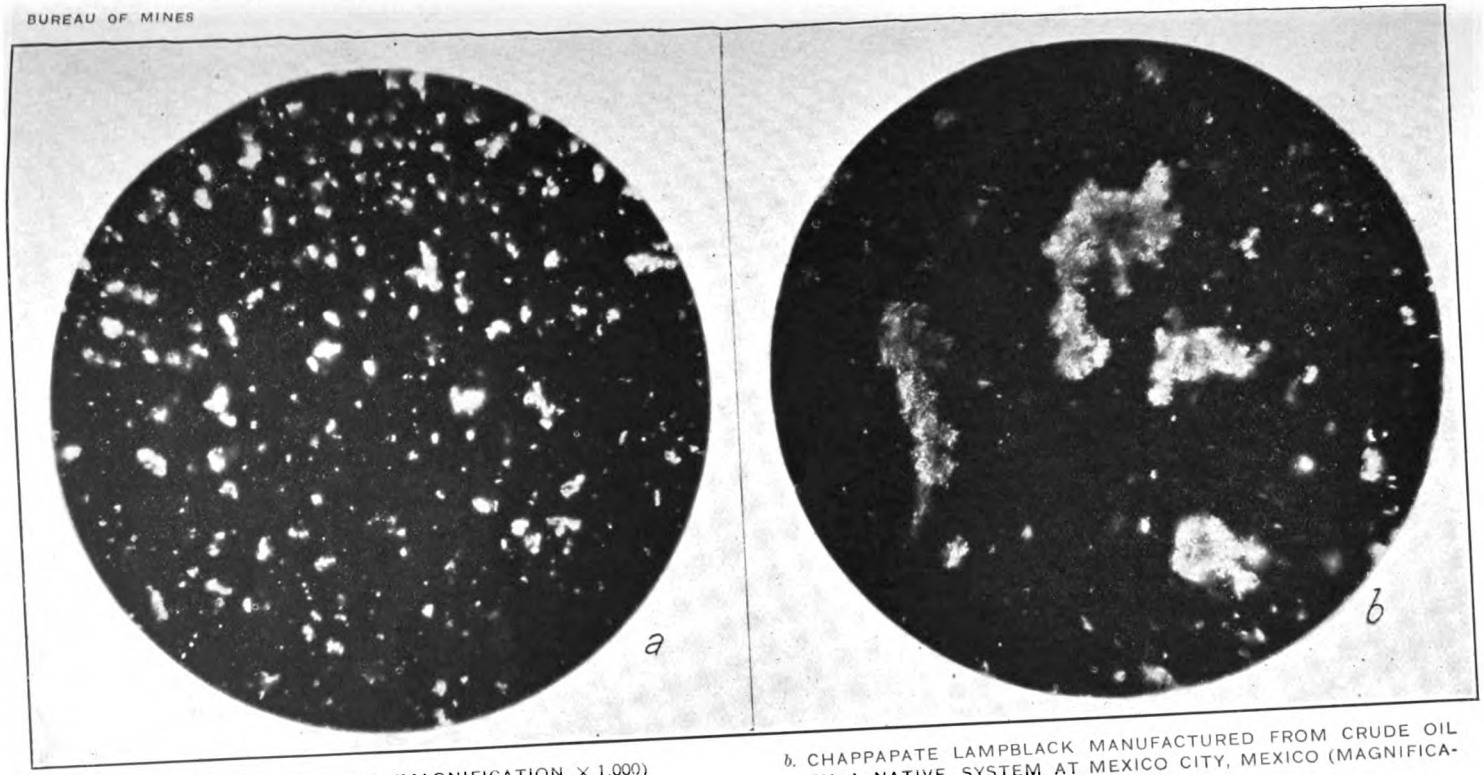

a. GERMAN LAMPBLACK (MAGNIFICATION, X 1,000)

b. CHAPPAPATE LAMPBLACK MANUFACTURED FROM CRUDE OIL BY A NATIVE SYSTEM AT MEXICO CITY, MEXICO (MAGNIFICATION, X 1,000)

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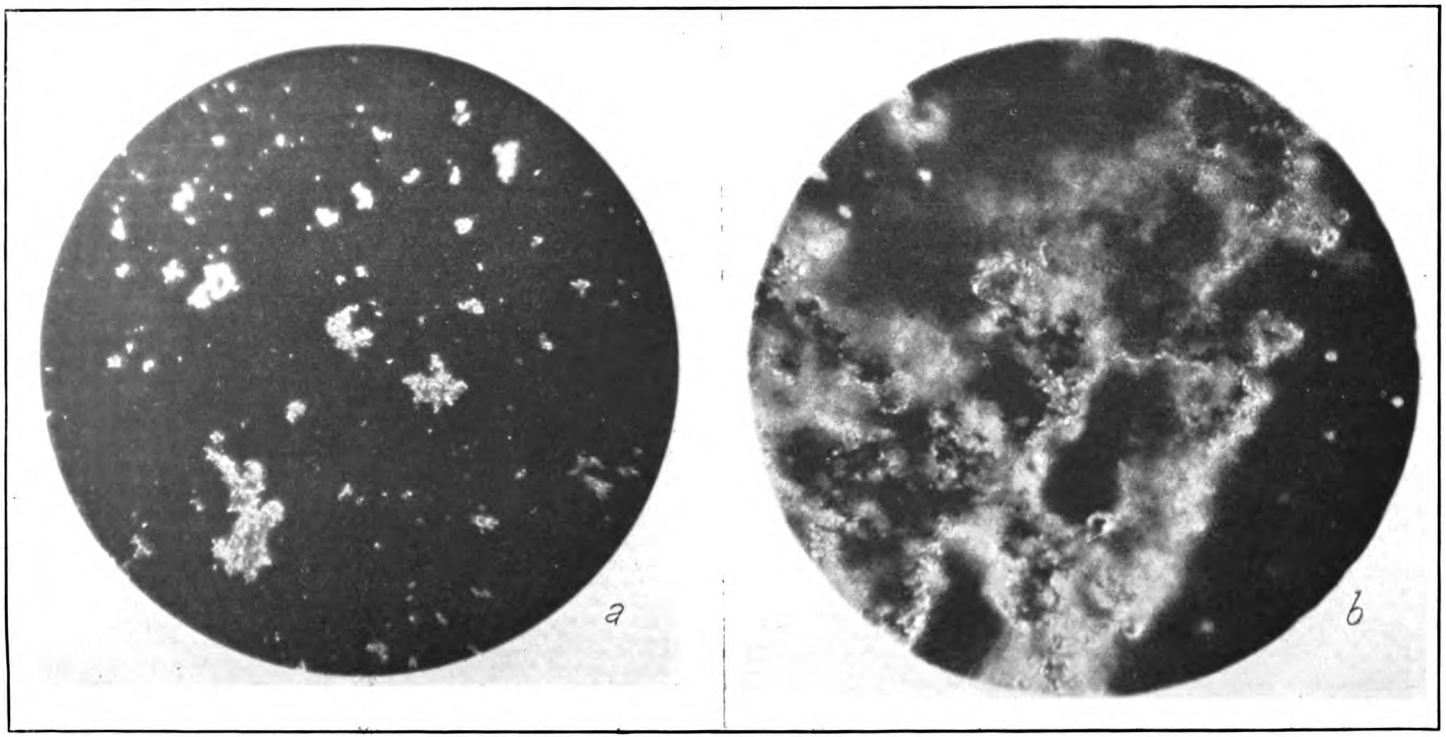

a. GERMAN LAMPBLACK. CONTENTS OF A SPRINGLUFT LAMPBLACK CARTRIDGE (MAGNIFICATION, X 1,000)

b. A THERMAL PROCESS BLACK (MAGNIFICATION, X 2,000)

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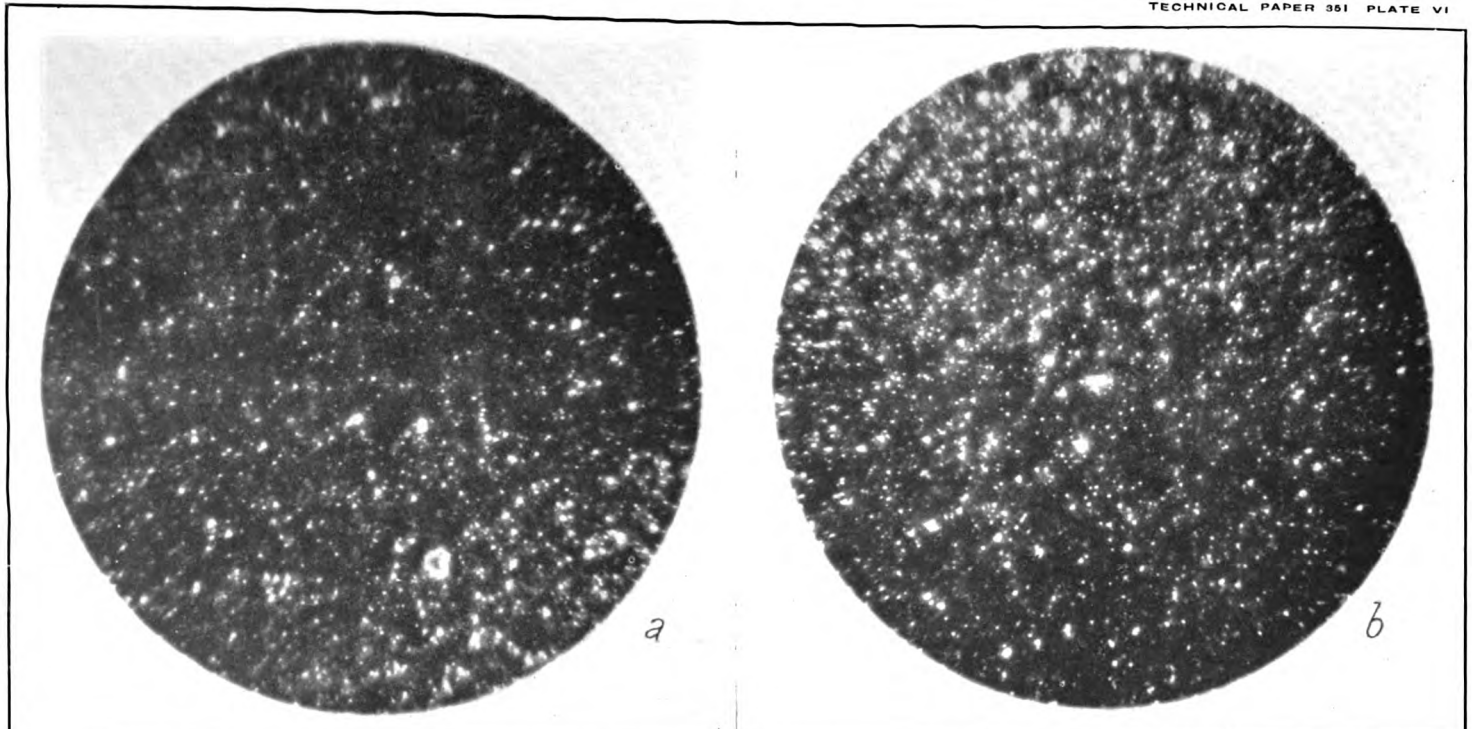

a. CARBON BLACK PRODUCED FROM KEROSENE (RUN NO. C-111). PHOTOMICROGRAPH TAKEN IMMEDIATELY AFTER PREPARATION OF SLIDE (MAGNIFICATION, X 1,000)

b. CARBON BLACK PRODUCED FROM KEROSENE (RUN NO. C-111). PHOTOMICROGRAPH TAKEN ONE WEEK AFTER PREPARATION OF SLIDE (MAGNIFICATION, X 1,000)

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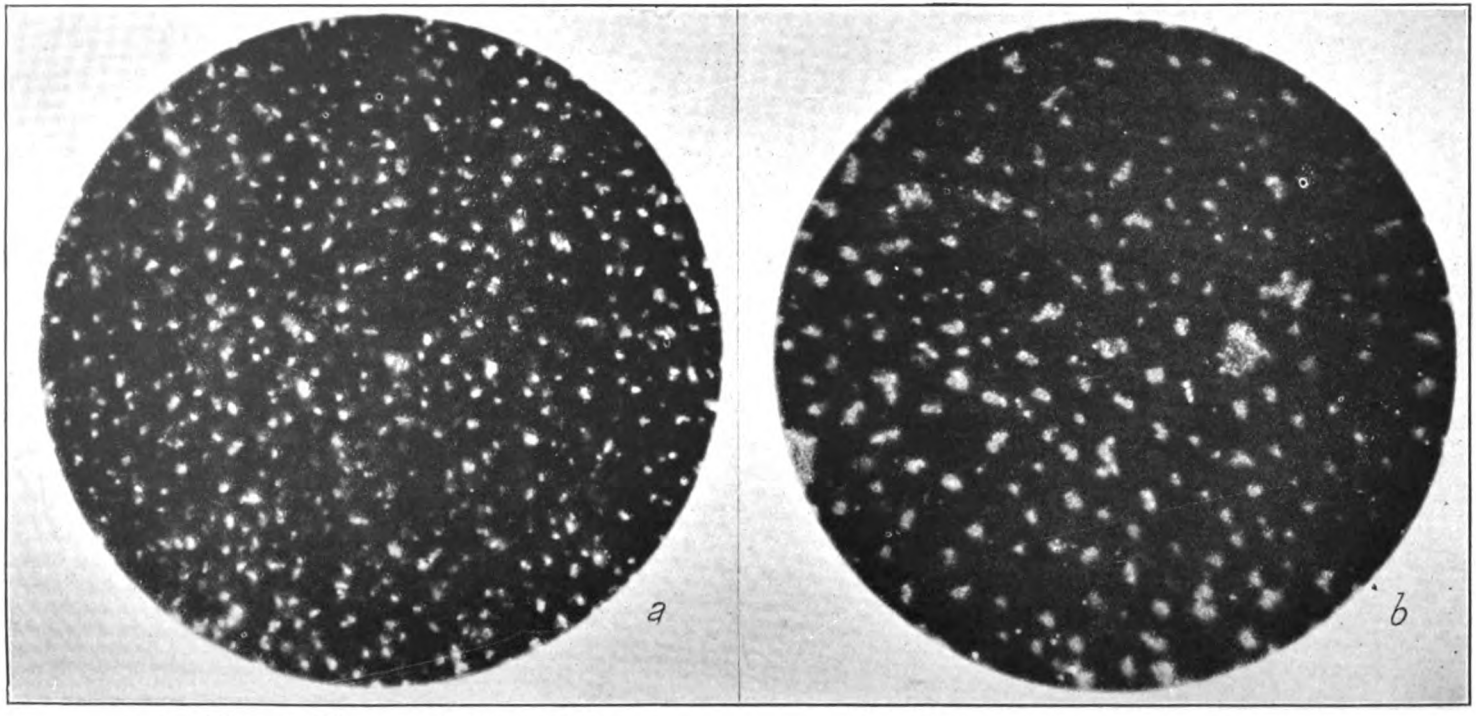

a. A "LONG" BLACK (MAGNIFICATION, X 2,000)

b. A "SHORT" BLACK (MAGNIFICATION, X 2,000)

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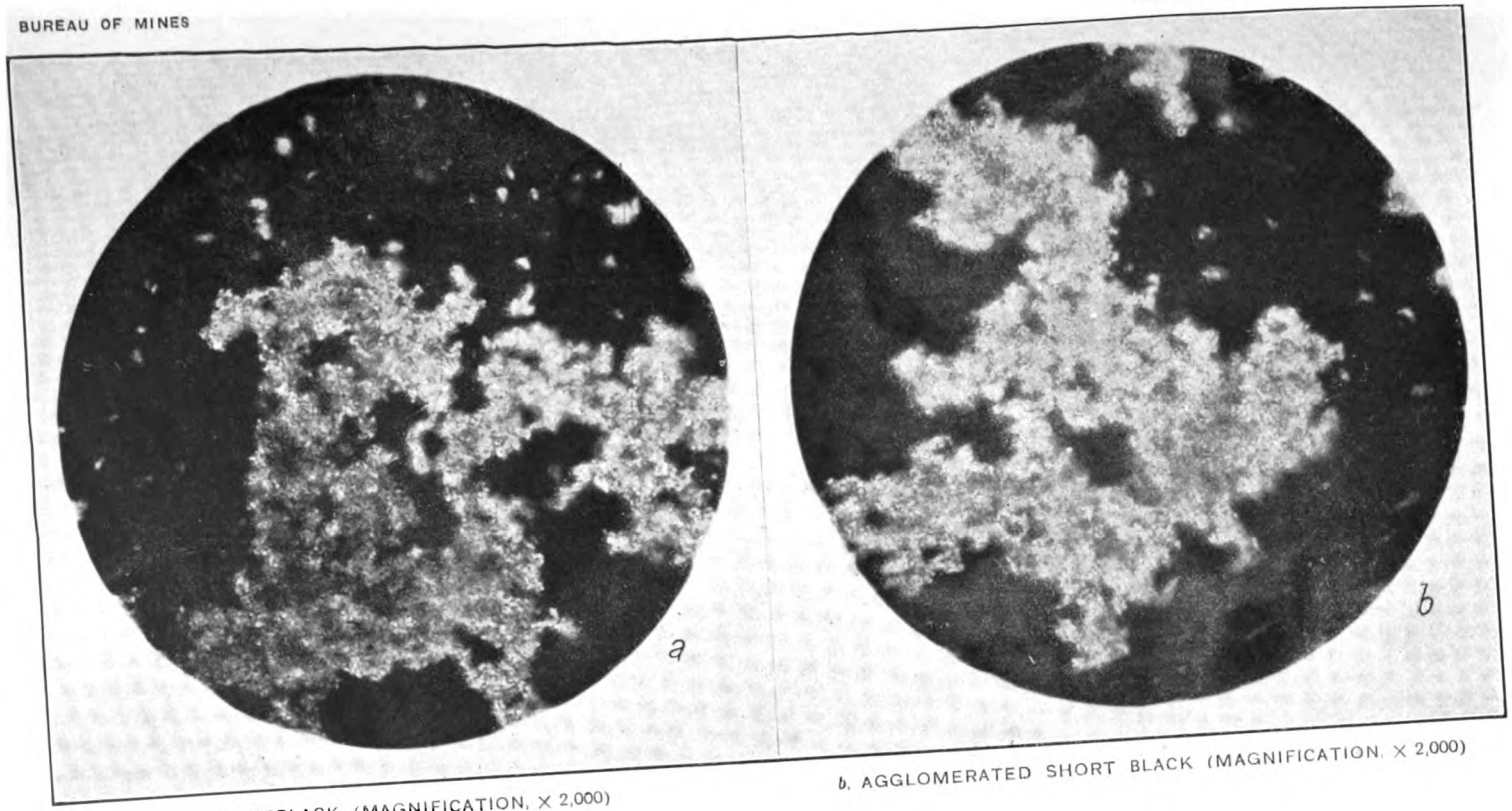

a. LAMPBLACK (MAGNIFICATION, × 2,000)

b. AGGLOMERATED SHORT BLACK (MAGNIFICATION, × 2,000)

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UTILIZATION OF RESIDUE PRODUCED DURING MANUFACTURE OF CARBON BLACK.

PRODUCTION OF ALCOHOL FROM UNSATURATED HYDROCARBONS.

It seems probable that the unsaturated gases produced during the decomposition of the oil may be profitably utilized for the manufacture of alcohols. In the arc the heavier, more complex hydrocarbons break down almost completely into carbon, hydrogen, and the gaseous members of the saturated and unsaturated series. Little, if any, light condensable hydrocarbons, such as gasoline, are formed during the process; and tests of an oil that had passed through the apparatus 15 times showed practically no change in specific gravity, unsaturation (as determined by the amount absorbed in concentrated sulphuric acid), initial boiling point, end point, and average boiling point.

The unsaturated hydrocarbons formed during the process are noncondensable at ordinary pressures; they probably consist almost wholly of ethylene, with some prophylene and other light homologues of the olefin series. The amount of these hydrocarbons formed during cracking varies with the kind of oil and its molecular weight, also with the current in the arc. For any given flow of current the proportion of unsaturates in the exit gases varies with the molecular weight of the hydrocarbon being decomposed, and the more complex the hydrocarbons the greater the proportion of unsaturates. Also, the greater the flow of current—which probably means higher arc temperature—the greater is the percentage of unsaturates. If the production of unsaturated gas instead of carbon black were desired, a heavy oil and a heavy current would probably give the best conditions.

PRODUCTION OF NONCONDENSABLE GASES.

In the electrical production of carbon black from oils, permanent gases are formed. The amount of these per pound of carbon black varies with the type of oil being treated and the electrical conditions within the treaters. Under the best conditions—that is, with minimum power input for each pound of black produced—the production of gas will be about 55 cubic feet per pound of black recovered. This gas will be suitable for domestic fuel as it has essentially the composition shown below.

Constituents of gas.

	Per cent.
Methane (CH_4)	10
Hydrogen (H_2)	50
Unsaturates	35
CO, CO_2, O_2, and H_2	5
	100

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A plant producing about 2,000 pounds of black a day will produce 2,000 times 55 cubic feet, which equals 110,000 cubic feet a day, or 33,000,000 cubic feet in a year of 300 operating days. This gas could probably be sold in those localities where a market exists for domestic gas, and would reduce thereby the total net cost of producing the carbon black.

If alcohol recovery or other use is made of the unsaturates in the gas, the hydrogen and other constituents remaining after the removal of the unsaturates may be used as fuel for reconcentrating the absorption sulphuric acid and for concentrating and rectifying the alcohol.

POWER-FACTOR CONSIDERATIONS.

The power factor of a high-voltage arc equipment will be comparatively low. The high-tension arc has normally a negative characteristic, and as the current increases the voltage across the gap decreases. Increased current means a higher temperature in the arc and greater velocity of the gaseous particles; the ionization increases, and the gap resistance drops. In order to make the arc more stable the reactance used must be fairly high, but the resistance of such reactances should be low and the heat losses should be minimized. With properly designed reactances or impedances, any change of current may be checked and a stable arc obtained; sometimes with such an impedance the current can be increased enough to cause the characteristic of the arc to change sign and become positive; thus an increase in current means only an increase in voltage. Such a condition would usually be desirable for the arc used in the production of carbon black by the processes described herein. In these experiments the power factor of the arcs ranged from 0.2 to 0.65. In industrial practice this low-power factor could be corrected by a suitable synchronous condenser or motor, which would decrease the abnormally large kilovolt-ampere installation required to supply such a plant, and incidentally would assure a more favorable rate from the company providing the electric power.

ECONOMIC CONSIDERATIONS.

The data available from the laboratory investigations described in this paper indicate that the electrical process has good industrial possibilities. It is impossible, of course, to estimate accurately from laboratory data the cost of producing carbon black electrically on a large scale.

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ESSENTIALS FOR MANUFACTURE OF CARBON BLACK.

For manufacturing carbon black from oils by the process described, the main essentials are cheap electric power and cheap light-oil distillates. As the process is simple, complicated special equipment is not necessary. Aside from the arc treaters themselves, apparatus for handling the oil and for the filtering, drying, and air separation of the black is of standard design. At most of the carbon-black works high-voltage current such as is available at power plants could be used directly and transformer stations would not be required, although suitable current-limiting reactances would be necessary.

ECONOMIES POSSIBLE.

The electrical process seems suitable for part-time or intermittent operation, and could, therefore, utilize the off-peak power available at many large hydroelectric and turbine power plants. As this off-peak power can be purchased at lower rates in most cities, carbon black could be made near the industries using it, and a considerable saving in freight rates alone could be effected. Especially will this be true as to certain markets in the Eastern United States. About 20 per cent of the carbon black made in the United States is exported to foreign countries. Plants at the sites of cheap power in Europe could supply much of this demand, but at present no carbon black is manufactured in Europe because large quantities of cheap gas are not available.

A plant manufacturing carbon black by this arc process will probably be composed of a series of separate units. By reason of the low cost per unit and the suitability of the process for intermittent operation, a plant composed of a multiple of units will be flexible enough to operate on a five-minute demand basis and to follow the available off-peak power curve fairly closely. Such a plant will be able to obtain the lowest existing rates for power. An abundance of cheap off-peak power may be obtained (1922) in practically all parts of the United States and foreign countries at rates ranging from about 1 mill to 5 mills per kilowatt hour.

The cost of producing carbon black by the process described will vary with the cost of electric power and the cost of the oil.

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CAPACITIES OF PRESENT CARBON-BLACK PLANTS.

Table 9 gives the capacities of 44 plants making carbon black.

TABLE 9.—*Capacity of carbon-black factories in six States.*[a]

State.	Total annual production of State.[b]	Number of plants in State.	Average yearly production per plant.	Average daily production per plant.[c]
	Pounds.		*Pounds.*	*Pounds.*
West Virginia	[d]28,000,000	27	1,037,000	3,456
Louisiana	20,000,000	12	1,666,000	5,555
Wyoming	4,500,000	2	2,250,000	7,500
Montana	2,000,000	1	2,000,000	6,660
Kentucky	1,600,000	1	1,600,000	5,333
Oklahoma	1,500,000	1	1,500,000	5,000

[a] Data partly taken from Neal and Perrott, work cited.
[b] Estimated.
[c] Calculated on a basis of 300 operating days in a year.
[d] Some of the plants have been moved to gas fields in other States or have been abandoned, so that the present capacity of the plants in this State is less than the production in 1918.

ESTIMATED COST OF PRODUCING CARBON BLACK BY THE ARC PROCESS.

In the following estimate of the cost of producing carbon black by the electric process, a plant with a capacity of 2,000 pounds a day is assumed. Table 9 shows that such a plant would be somewhat smaller than the average carbon-black plant now in operation, hence the overhead charges per pound will be greater than in a larger plant. A plant with a capacity of 2,000 pounds a day (300 operating days in a year) will supply only about 1 per cent of the present consumption of black, or about 600,000 pounds of black a year.

At present it is impossible to estimate accurately the cost of large units, but from available data, on the assumption that a large-scale plant would be built after the general plan of the laboratory equipment, the cost of a complete plant, including railroad siding, average plant site, electric treaters, settling and storage tanks, filtering equipment, pulverizing and separating equipment, sacking and cooperage plant, pumps, piping, valves, etc., engineering charges and superintendence of erection, development work, and the changes usually necessary in adjusting a new plant to smooth operation is approximately $55,000.

The estimated cost per pound-day output is therefore approximately 55,000÷2,000=$27.50. Plants now producing carbon black by the channel process cost $35 to $50 per pound-day output.[6]

The following estimate gives the costs of producing carbon black, on the assumption of an initial investment of $55,000.

[6] See Neal, R. O., and Perrott, G. St. J., work cited, page 43, for additional figures on cost.

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OPERATING COSTS.

FIXED CHARGES.

Interest on investment, 6 per cent on $55,000	$3,300
Depreciation (assuming plant to be valueless at end of 10 years), 7.58 per cent on $55,000	4,170
Taxes, 1 per cent on $55,000	550
Insurance, 2 per cent on $55,000	1,100
Plant administration (included under labor.)	
General property and plant repairs, 2 per cent on $55,000	1,100
Total fixed charges	10,220
Total fixed charges per pound of black, $10,220÷600,000=(cents)	1.72

RAW MATERIALS AND SUPPLIES.

Unrefined light-oil distillate (assuming only 3 pounds of carbon black recovered per gallon of oil treated), 600,000÷3×$0.07	$14,000
Replacement of wash oil	1,500
Electric power (assuming a plant operating efficiency of 15 kilowatt hours per pound), 15 kw. h. × 600,000×$0.002 per kw. h	18,000
Oil, waste, and supplies, 2 per cent on $55,000	1,100
Total cost of material and supplies	34,600
Per pound of black, $34,600÷600,000=(cents)	5.76

PLANT SUPERINTENDENCE AND LABOR.

NOTE.—Labor allowed for operating the plant is as follows: Treater operators, night shift—two men come to work at close of day shift and work from 5 p. m. to midnight; second operators work from midnight to 7 a. m. (Treaters run on off-peak load between 6 p. m. and 6 a. m.)

Filtering, pulverizing, separating, and sacking equipment operators and other laborers work from 7 a. m. to 5 p. m. All costs are for full crews per annum, but output is figured for plant running only 300 days a year.

1 plant foreman, at $2,500	$2,500
1 clerk (bookkeeper, timekeeper, etc.), at $1,400	1,400
4 treater operators, at $1,600	6,400
2 filter and mill operators, at $1,600	3,200
2 packers, at $1,500	3,000
	16,500
Liability insurance, at 5 per cent	825
Total labor cost	17,325
Total labor cost per pound of black, 17,325÷600,000=(cents)	2.89

SUMMARY.

Fixed charges, per pound (cents)	1.72
Raw materials and supplies, per pound (cents)	5.76
Labor, per pound (cents)	2.89
Total cost per pound of black, assuming no market exists for the noncondensable gas or that the unsaturated gases can not be utilized (cents)	10.37

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CONCLUSIONS.

1. A process for making carbon black directly from oils seems to possess advantages over present methods of making the black by incomplete combustion of natural gas. In certain States the decreasing supply of natural gas, and drastic legislation against carbon-black plants, has prevented the expansion that would be economically justified by the increasing use of carbon black in the industries and the gradual rise in price for the better grades of black. At present, Louisiana is the center of carbon-black production in the United States, and the black has to be shipped comparatively long distances to the chief markets, at freight rates that are high because of the bulkiness of the black.

2. In the manufacture of carbon black from oils, by the arc process described in this paper, the two main essentials are a cheap electric power and cheap light-oil distillates. The process is suitable for noncontinuous or intermittent operation and could, therefore, utilize some of the cheap off-peak power available in practically all parts of the United States and in many foreign countries. Because of the abundance of cheap off-peak power in nearly all large industrial centers, carbon black in many places can be manufactured where it is needed, with a considerable saving in freight rates alone. Especially will this be true as to certain eastern States and as to foreign markets. Prices for second-class power differ considerably with local conditions, but enough power is available in well-scattered regions of this country at prices ranging from 0.01 cent to 0.05 cent per kilowatt hour. Power in many foreign countries is considerably cheaper.

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